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(U.S.) Tennessee Valley Authority, Decatur, AL

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Browns Ferry Biothermal Research Series

II. Effects of Temperature on Bluegill and Walleye, and Periphyton, Macroinvertebrate, and Zooplankton Communities in Experimental Ecosystems

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August 1979

BROWNS FERRY BIOTHERMAL RESEARCH SERIES
II. EFFECTS OF TEMPERATURE ON BLUEGILL AND WALLEYE, AND PERIPHYTON, MACROINVERTEBRATE, AND ZOOPLANKTON COMMUNITIES IN EXPERIMENTAL ECOSYSTEMS

by

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FOREWORD

The aquatic environment must be protected from the adverse effects of thermal discharges. Large volume thermal discharges, if not properly managed, can have deleterious effects on fish populations and their food-chain organisms and thus ultimately diminish the quality of man's environment; conversely, excessive control measures can result in inefficiencies in energy use and economic penalties to the public. A balance must therefore be maintained between the industrial utilization of water and the maintenance of a high-quality environment. The Browns Ferry Biothermal Research Program contributes to the search for this acceptable balance through investigations on

--the effects of increased temperature on growth, survival and reproduction of sport and commercially important fish species and their food organisms, and

--the effects of increased temperature on the ecological relationships between fish and their food organisms.

This report presents the results of the first full-scale experiment with heated water at the Biothermal Research Station. Specifically, this report addresses the effects of elevated thermal regimens on two important fish species, bluegill (*Lepomis macrochirus*) and walleye (*Stizostedion v. vitreum*) and on population and community responses of macroinvertebrates, zooplankton and periphyton. In doing so, it presents significant new data on thermal effects relative to longer acclimation periods and higher acclimation temperatures than previously reported.

Clyde W. Voigtlander
Office of Natural Resources
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ABSTRACT

The

Effects of long-term, March-September 1977, temperature elevations on aquatic communities in 12 outdoor experimental channels were evaluated. Macroinvertebrates, periphyton, and zooplankton colonized the channels naturally from the water supplied from Wheeler Reservoir, Tennessee River. The fish community consisted of stocked adult bluegill and juvenile walleye. Four temperature regimens, with three replicate channels per regimen, were maintained. The ambient temperature of the water pumped from Wheeler Reservoir provided the lowest treatment. Elevated regimens of ca. 2°, 4°, and 6° C above ambient were maintained in the remaining nine channels.

The work upon which this publication is based was performed pursuant to an Interagency Agreement between the Tennessee Valley Authority and the Environmental Protection Agency. This report was submitted in partial fulfillment of Contract No. TV-35013A by the Tennessee Valley Authority under partial sponsorship of the U.S. Environmental Protection Agency. The report covers field work from March 1977 to September 1977, and analyses completed as of August 1978.

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SECTION 1

INTRODUCTION

of the study

This report covers the first full-scale experiment with heated water at the Browns Ferry Biothermal Research Station, funded jointly by the Environmental Protection Agency (EPA) and the Tennessee Valley Authority (TVA) in recognition of their common interests and concerns regarding energy production and environmental protection. The primary feature of the facility, located on the Tennessee River in northern Alabama, is a series of 12 temperature-controlled outdoor channels designed to assess the thermal requirements of fish and other aquatic organisms under essentially natural conditions (e.g. seasonal and diurnal temperature fluctuations, photoperiod, and predator-prey interactions). The major objective is to provide information for establishing temperature criteria for protection of important sport and commercial fish species; moreover, since the channels are colonized by diverse algal, macroinvertebrate, and zooplankton communities, temperature criteria also can be evaluated in relation to protection of the ecological intergrity (Cairns, 1977) of an aquatic ecosystem. Documentation of the algal and invertebrate organisms which have colonized the channels, and a description of the facility were provided by Armitage *et al.* (1978). A summary of the physical characteristics of the channels is presented in Table 1.

In general, evaluation of thermal requirements of fish species tested in the experimental channels follows the protocol described by Brungs and Jones (1977), i.e. determining mean and maximum numerical criteria based on the protection of desirable or important species. Primary emphasis is on determining the long-term or chronic effects of elevated thermal regimens on growth, survival, and reproduction. Initially, this facility was designed to test warmwater species; however, species now recognized as coolwater forms (e.g. sauger and walleye) (Hokanson, 1977; Kendall, 1978) will also be evaluated. Species tested in the channels are selected by three criteria: (1) contributing information on important species as identified by EPA and TVA, (2) inhabiting the Tennessee River, and (3) adaptation to the channel environment.

OBJECTIVES

This experiment, with bluegill (*Lepomis macrochirus*) and walleye (*Stizostedion vitreum vitreum*) as the target fish species, was conducted from 3 March to 8 September, 1977, in 12 outdoor experimental channels. Four temperature regimens (treatments), with three replicate channels per regimen were established. The ambient temperature of Wheeler Reservoir (Tennessee River) provided the lowest regimen. The three elevated

TABLE 1. PHYSICAL CHARACTERISTICS OF EACH OF THE 12 EXPERIMENTAL CHANNELS AT THE BROWNS FERRY BIOTHERMAL RESEARCH STATION.

Characteristic	Metric Units
Channel length (total)	114 m
Channel length (water surface)	112 m
Channel width	4.3 m
Channel depth	2.10 m
Water depth over pool areas	1.2 m
Water depth over rock areas	0.3 m
Water surface area	0.048 hectares 480 m^2
Water volume	530 m^3
Water discharge rate	0.66 m^3/min
Water turnover time	14 hrs
Number of pool areas	6
Pool substrate type	50-cm layer of reservoir sediments
Water velocity in pool areas	0.14 m/min
Number of rock areas	6
Rock type	5-15 cm rocks of crushed limestone
Water velocity over rock areas	0.56 m/min

temperature regimens, superimposed on the seasonal and diurnal temperature cycle of the reservoir, were +2 C, +4 C, and +6 C.

Specific objectives in evaluating effects of the elevated thermal regimens were:

1. Determination of production and biomass of adult bluegill and juvenile walleye.
2. Determination of production and biomass of young-of-the-year bluegill.
3. Evaluation of bluegill reproduction.
4. Evaluation of both population and community responses of macroinvertebrates on the basis of species composition, relative biomass and density, and life cycle turnover rates.
5. Determination of species composition and relative biomass and density of zooplankton.
6. Determination of biomass, community structure, and metabolic activity of the periphyton.

REFERENCES

Armitage, B. J., T. D. Forsythe, E. B. Rodgers, and W. B. Wrenn. 1978. Colonization by periphyton, zooplankton, and macroinvertebrates. Browns Ferry Biothermal Res. Ser. I. U.S. Environ. Prot. Agency, Duluth, Minn., EPA-600/3-78-020. 46 pp.

Brungs, W. A., and B. R. Jones. 1977. Temperature criteria for freshwater fish: protocol and procedures. U.S. Environ. Prot. Agency, Duluth, Minn., EPA-600/3-77-061. 130 pp.

Cairns, J., Jr. 1977. Aquatic ecosystem assimilative capacity. Fisheries 3(2): 5-7.

Hokanson, K.E.F. 1977. Temperature requirements of some percids and adaptations to the seasonal temperature cycle. J. Fish. Res. Board Can. 34(10): 1524-1550.

Kendall, R. L. (ed.). 1978. A symposium on selected coolwater fishes of North America. Special Publ. No. 11, Amer. Fish. Soc., Washington, D.C., 437 p.

SECTION 2

CONCLUSIONS

1. Twelve outdoor experimental channels, naturally colonized by diverse periphytic and invertebrate communities and stocked with a forage (bluegill) and a predator (walleye) fish species, simulated natural aquatic ecosystems which provided a unique opportunity to evaluate long-term effects of elevated temperature regimens on aquatic communities and on species, as well.

2. Elevated temperature regimens (ca. 2°, 4°, and 6° C above the ambient temperature of Wheeler Reservoir, Tennessee River) which ranged from ca. 31° to 34° C for more than 70 days had no significant effect on the production and biomass of bluegill.

3. The only temperature effect on bluegill reproduction was the earlier inception of spawning in the elevated regimens. Hatching success of eggs was 95% at 34° C.

4. Young-of-the-year bluegill provided an abundant food source for the walleye.

5. The biomass of juvenile walleye was highest in the ambient regimen (which exceeded 28° C for 78 days) but this was not significantly greater than the biomass of walleye held in an elevated temperature regimen which reached 32° to 33° C for 75 days.

6. Total mortality of the walleye in the highest temperature regimen occurred at ca. 34° C.

7. Walleye in this study were more temperature-tolerant than previously indicated by laboratory studies. The longer acclimation period, higher acclimation temperatures, and the predator-prey conditions in the channels apparently influenced this higher tolerance.

8. Elevated temperature regimens ranging from ca. 31° to 34° C for more than 70 days were not of sufficient magnitude to cause measurable stress to the zooplankton community structure. The dominant zooplankters were the copepod *Mesocyclops edax*, the ostracod *Physocypria* sp., and the cladocerans *Bosmina longirostris*, *Chydorus sphaericus*, and *Simocephalus vetulus*.

9. Although young bluegill predation on zooplankton had a significant effect on abundance and species composition, temperature had no apparent

effect on the biomass of young bluegill directly affecting zooplankton turnover rates.

10. A greater monthly and total biomass of floating algal mats (algal export) was produced in the warmest temperature treatment.

11. Within both the floating mats and the attached algal wall communities, shifts in dominance and succession were accelerated in the warmest treatment.

12. The attached algal wall communities provided no clear indications of thermal effects in terms of biomass.

13. The accelerated algal succession and increased biomass accumlation in the heated channels apparently increased the herbivore food supply during the spring and early summer, while apparently decreasing the food supply during the late summer.

14. Numerically dominant macroinvertebrates evaluated from March through August were: *Physa heterostropha* (Gastropoda), *Hyalella azteca* and *Crangonyx* sp. (Amphipoda), *Caenis* sp. (Ephemeroptera), and Chironomidae (Diptera).

15. Neither Chironomidae nor *Physa heterostropha* densities or biomass were affected by elevated temperatures in any consistent way.

16. Amphipoda responded inversely to increased temperature, both in terms of peak biomass and duration of population existence.

17. *Caenis* sp. and Chironomidae showed accelerated life cycles.

18. The relative decimation of the macroinvertebrate community in warmer channels in late summer was not reflected in the biomass of bluegill recovered at the end of the experiment.

19. Neither diversity index nor percent abundance data were useful in defining temperature effects.

20. Future studies should be directed toward (a) determining whether the macroinvertebrate community decimated by temperature elevation would recover during a longer study (1.5-2 yr), and (b) determining food sources of bluegill during periods of macroinvertebrate community decline.

SECTION 3

TEMPERATURE AND WATER QUALITY

INTRODUCTION

The water supply system for the biothermal channels is designed so that up to four temperature regimens, with three channels per regimen, can be established simultaneously. Multiple inlet pipes and valves allow randomization (by sets of three) in the application of the temperature regimens (Fig. 1). Water pumped from Wheeler Reservoir, which is the source for all 12 channels, provides the lowest temperature regimen. Three elevated temperature regimens, superimposed on the seasonal and diurnal temperature cycle of the reservoir, can be established by passing the inflowing ambient water through heat exchangers (with stainless-steel tube bundles) before entering the channels. The heat source for the exchangers is the condenser cooling water pumped from the Browns Ferry Nuclear Plant.

Flow rates (0.66 m^3/min or 180 gal/min per channel) and the physical dimensions of the channels are such that elevated increments established at the inlet are expected to be maintained at "constant" levels (± 1° C) only in the upper 44 m of the channels. Downstream from this point, the temperature usually begins to decline so that a zone of thermal gradients occurs in the lower 68 m of the channels. In order to have the option of confining fish to the upper "constant" section in a given treatment, the channels were constructed so that fine mesh (2 mm) screen barriers could be installed to divide the channels into upper and lower sections of 190 and 290 m^2, respectively. The upper channel sections of the elevated temperature regimens are considered to simulate conditions that would occur if the temperature increased (either naturally or induced by man) in an entire water body so that cooler refuge areas would not be available to the fish or other mobile organisms. Temperature conditions in the lower section of a divided channel or in an undivided channel, simulate thermal plumes such as those associated with heated discharges from power plants. In the case of an undivided channel, the highest temperature in the plume would impact ca. 40% of the mixed water body (channel), but the fish would not be prevented from seeking cooler zones along a thermal gradient or vice versa.

TEMPERATURE

In the present study, two of the three channels for each temperature regimen were divided, and the third was undivided. The nominal elevated temperature regimens were 2, 4, and 6° C above the ambient reservoir temperature. Actual temperature regimens maintained are presented in

Figure 2. These regimens were based on daily mean temperature at 1 m, which represented the average minimum temperature accessible to the bluegill and walleye. Diurnal temperature changes in the upper sections seldom exceeded 2° C. For the upper sections temperature was measured at the inlet and 38 m, and in the lower sections at 70 and 102 m. Temperature was measured (Honeywell RT/1 Transmitter, Resistance thermometer-to-current) at hourly intervals at these four locations and the data stored by computer. To check the automatic monitors, temperatures were measured two days each week at 0700 and 1530 hours with a calibrated (ASTM), portable electrical thermometer (Table 2). Temperatures at 0.3 m were also monitored at this time to evaluate vertical differences (Table 3 and 4). As expected, vertical temperature differences were more pronounced in the lower sections. Vertical differences in the lower sections were also indicative of the range of horizontal temperatures that could be selected by the fish in these sections Abrupt declines in the elevated regimens (Fig. 2) were caused by valve failures or the loss of heat from the nuclear plant (unit outage or load reduction). Precise flow control was usually maintained to each channel (180 gal/min); this was accomplished with Jamesbury ball valves and electronic accuators in combination with Honeywell diffused silicon ΔP (flow) transmitters.

WATER QUALITY

Most water quality parameters were estimated using methods outlined in Standard Methods (1976). Underwater light transmittance (%) was estimated at 0.3, 0.6, and 0.9 m using a Montedoro-Whitney Submarine Photometer. Total gas saturation and N_2-Ar saturation were estimated with a Weiss Saturometer. Dissolved oxygen was measured two days per week from each channel. Measurements were made with a YSI portable meter at 0700 and 1600 hrs at 0.3 and 0.9 m in the upper section (second pool) and lower section (sixth pool).

Water quality was monitored to insure no abnormal chemical or physical events, except temperature, affected the results. As can be seen from the mean values listed in Table 5, very few parameters differed among temperature treatments.

Minimum values for dissolved oxygen at 0.9 m in the heated channels (upper sections), although only half those in the ambient channels, seldom dropped below 4 ppm. This decline is probably indicative of higher respiration rates in the sediments by microorganisms stimulated by increased temperature. Greater light penetration in the ambient channels were indicated by secci disk and light photometer measurements. Complementing this difference between ambient and heated channels was the lower mean nonfilterable residue in the ambient channels. Apparently, temperature-stimulation of planktonic populations in the upper sections of the heated channels accounted for the decrease in light penetration and the increase in nonfilterable residue. Support for this effect is drawn from infrequent carbohydrate analyses of plankton samples which indicated increased total carbohydrate with increased temperature treatment (e.g. June 9, 1977: ambient = 178, +2 = 206, +4 = 215, +6 = 231 μg total carbohydrate/liter). Increases in pH between upper and lower sections was a natural result of photosynthetic activity which assimilated carbon dioxide and drove the bicarbonate equilibrium to the right.

Examination of data (not presented) from atomic absorption analyses of dissolved metal species indicated no variation between heat treatments. Also, levels of some metals (e.g. Fe) were at higher concentrations (but not toxic) than those reported from Wheeler Reservoir (Water Quality Branch, TVA). These higher concentrations resulted from the position of the cold water intake pipe, 7.6 m deep, in the overbank area of Wheeler Reservoir. Water from this area would be expected to vary from normal samples taken from mid-channel due to the greater influence of the sediment layers as a source of metal species. Samples from the intake pool of the Browns Ferry Nuclear Plant exhibited similarly raised concentration levels over mid-channel samples.

In conclusion, data derived from biweekly, monthly, and quarterly water quality monitoring did not indicate levels or concentrations which would affect the results of the temperature-dependent experiments. Differences of a few parameters among heat treatments were indicative of temperature effects.

REFERENCES

American Public Health Association, Inc. 1976. *Standard Methods for the Examination of Water and Wastewater.* 14th ed. Washington, D.C.

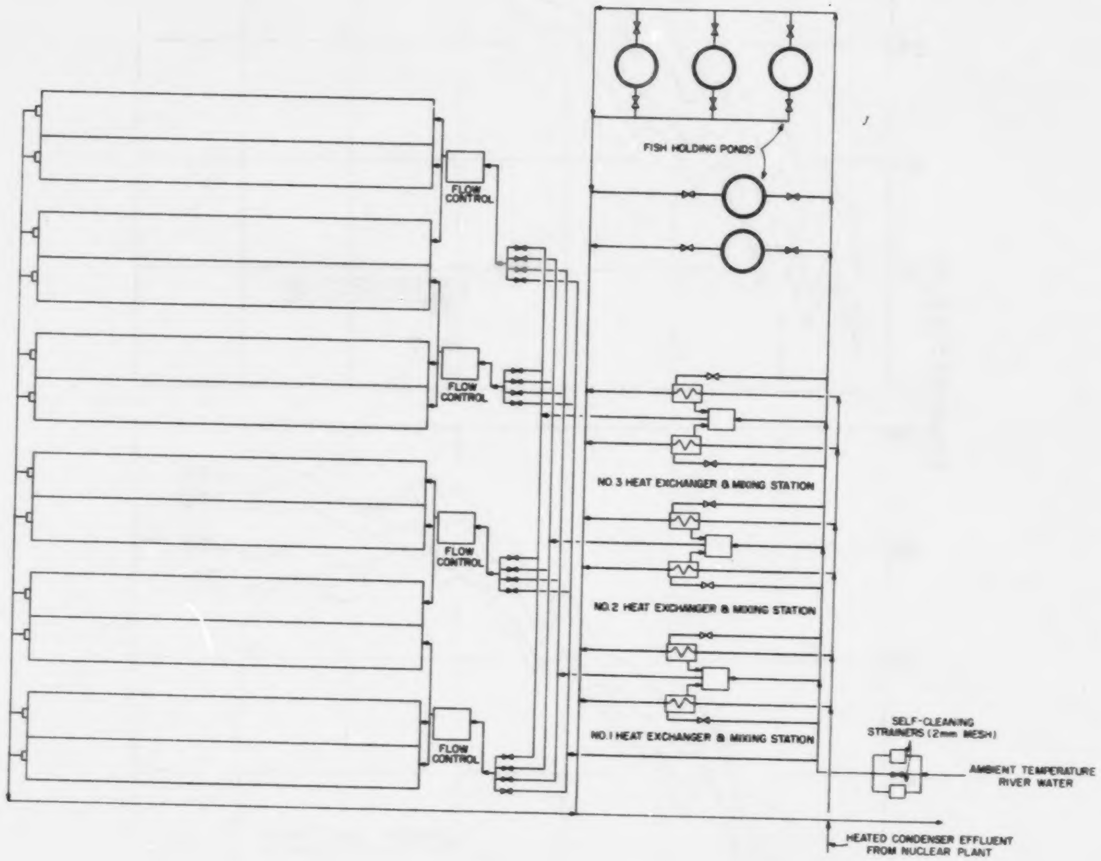
FISH HOLDING PONDS
FLOW CONTROL
FLOW CONTROL
FLOW CONTROL
FLOW CONTROL
NO 3 HEAT EXCHANGER & MIXING STATION
NO.2 HEAT EXCHANGER & MIXING STATION
NO.1 HEAT EXCHANGER & MIXING STATION
SELF-CLEANING STRAINERS (2mm MESH)
AMBIENT TEMPERATURE RIVER WATER
HEATED CONDENSER EFFLUENT FROM NUCLEAR PLANT

Figure 1. Schematic diagram of the water supply system, Browns Ferry experimental channels.

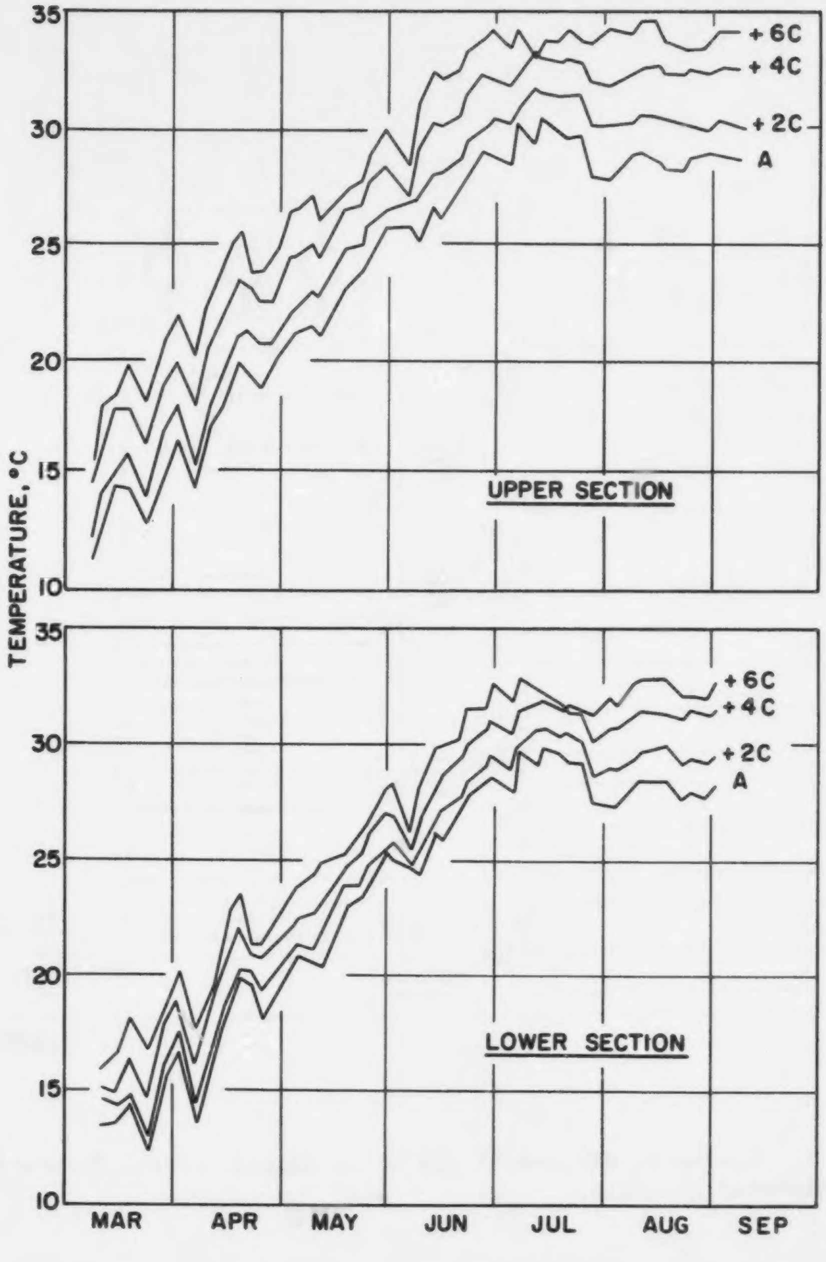

Figure 2. Average minimum daily temperature in experimental channels, 1977; A = ambient temperature regimen of Wheeler Reservoir (Tennessee River). Upper section included 40% of the area of each channel.

TABLE 2. COMPARISON OF MEAN DAILY WATER TEMPERATURES AT 1.0 m IN UPPER SECTIONS OF THE CHANNELS, 1977, AS DETERMINED BY AUTOMATIC AND MANUAL MEASUREMENTS (A = AMBIENT, B = +2 C, C = +4 C, D = +6 C).

Day of Year	A		B		C		D	
	Auto.*	Man.†	Auto.	Man.	Auto.	Man.	Auto.	Man.
67	11.2	10.6	12.3	12.3	14.5	14.0	15.6	15.0
70	12.8	12.7	14.3	14.1	16.1	16.0	18.0	17.8
74	14.5	14.2	15.1	15.7	17.9	17.0	18.5	18.8
78	14.4	14.7	15.9	16.1	17.9	18.1	19.8	19.8
83	12.8	-	14.0	-	16.2	-	18.1	-
88	15.0	14.9	16.8	16.9	18.8	18.7	20.5	21.1
92	16.5	-	18.0	-	19.9	-	21.9	-
97	14.4	-	15.5	-	17.9	-	20.0	-
101	17.0	17.0	17.8	18.5	20.5	20.4	22.6	22.6
104	17.7	-	18.9	-	21.4	-	23.4	-
108	19.3	19.0	20.4	20.8	22.8	22.7	24.9	25.1
110	19.9	-	21.0	-	23.4	-	25.4	-
113	19.5	-	21.2	-	23.1	-	23.7	-
116	18.6	18.6	20.7	20.5	22.4	22.2	23.7	23.0
118	19.5	19.0	20.6	19.8	22.3	20.9	24.2	22.4
123	20.7	20.0	21.8	21.7	24.2	23.8	26.3	26.0
125	21.0	21.2	22.1	21.8	24.4	24.0	26.4	25.9
130	21.3	21.5	22.9	22.9	24.9	24.4	27.1	27.1
132	20.9	21.2	22.6	22.4	24.3	24.5	25.9	26.8
139	22.9	23.0	24.6	24.4	26.4	26.0	27.1	26.6
144	23.6	23.9	24.8	24.7	26.6	26.4	27.6	27.2
146	24.1	23.9	25.7	25.3	27.5	27.1	28.6	28.1
151	25.6	25.5	26.3	25.9	28.1	27.5	29.8	29.2
153	25.4	25.9	27.1	27.9	28.8	28.8	30.4	30.6
158	25.7	25.7	26.7	26.9	27.0	27.2	28.2	28.6
160	25.1	24.8	26.8	26.3	28.8	28.2	30.8	29.8

* Mean daily temperature as determined from hourly intervals - automatic monitors.

† Mean daily temperature as determined from manual measurements at 0700 and 1530 hours.

(continued)

Table 2 (continued).

Day of Year	A		B		C		D	
	Auto.	Man.	Auto.	Man.	Auto.	Man.	Auto.	Man.
165	26.6	26.7	28.0	28.1	30.1	29.8	32.3	32.0
167	25.9	26.1	28.0	28.0	30.0	29.8	32.1	31.7
172	27.2	27.5	28.5	22.4	30.4	30.1	32.5	32.5
174	27.8	28.0	29.3	29.2	31.3	30.9	33.1	33.3
179	28.9	29.0	29.8	29.6	32.2	32.4	33.6	33.7
181	28.9	28.7	30.2	30.0	32.1	31.7	34.0	33.8
186	28.4	28.7	30.0	30.1	31.7	32.0	33.4	33.6
188	30.1	29.9	30.8	30.7	32.4	32.5	34.2	34.2
193	29.2	29.3	31.6	31.7	33.1	32.9	32.9	32.1
195	30.3	30.1	31.4	31.4	32.9	32.7	33.6	33.1
200	29.7	29.9	31.3	31.2	32.7	32.5	33.6	32.7
202	29.4	29.6	31.3	31.3	32.9	33.0	34.1	33.0
206	29.5	-	31.3	-	32.8	-	33.6	-
207	-	29.4	-	31.3	-	33.1	-	34.7
209	27.7	28.2	30.0	30.1	31.9	32.2	33.5	33.8
214	27.6	28.4	29.9	30.1	31.7	31.9	34.2	33.6
216	27.9	28.3	30.0	30.0	31.9	31.9	34.1	34.0
221	28.7	29.2	30.1	30.0	32.2	32.7	33.9	34.5
223	28.8	29.3	30.4	30.1	32.5	32.5	34.5	34.0
228	28.5	29.7	30.4	31.0	32.6	33.1	34.4	33.1
230	28.1	28.7	30.3	30.4	32.2	32.1	33.6	34.1
235	28.0	28.5	30.0	30.0	32.2	32.5	33.3	33.5
237	28.5	28.8	30.0	30.2	32.4	32.7	33.2	33.5
242	28.7	28.6	29.8	29.9	32.3	32.7	33.3	33.7
244	28.7	29.1	30.3	30.5	32.5	32.9	34.1	34.3

TABLE 3. REPRESENTATIVE MEAN DAILY SURFACE (0.3 m) AND BOTTOM (1.0 m) WATER TEMPERATURES IN THE UPPER SECTIONS OF THE CHANNELS 1977 (A = AMBIENT, B = +2 C, C = +4 C, D = +6 C).

Day of Year	A		B		C		D	
	0.3 m	1.0 m	0.3 m	1.0 m	0.3 m	1.0 m	0.3 m	1.0 m
67	-	10.6	-	12.3	-	14.0	-	15.0
70	-	12.7	-	14.1	-	16.0	-	17.8
74	-	14.2	-	15.7	-	17.0	-	18.8
78	-	14.7	-	16.1	-	18.1	-	19.8
88	-	14.9	-	16.9	-	18.7	-	21.1
101	-	17.0	-	18.5	-	20.4	-	22.6
108	19.9	19.0	21.4	20.8	22.9	22.7	25.1	25.1
116	18.8	18.6	21.0	20.5	22.3	22.2	23.3	23.0
118	19.3	19.0	20.1	19.8	21.1	20.9	22.7	22.4
123	21.1	20.0	22.2	21.7	24.1	23.8	26.0	26.0
125	21.6	21.2	22.9	21.8	24.8	24.0	26.8	25.9
130	21.5	21.5	23.2	22.9	24.7	24.4	27.1	27.1
132	21.5	21.2	23.0	22.4	24.8	24.5	27.0	26.8
139	23.6	23.0	25.1	24.4	26.9	26.0	27.4	26.6
144	24.1	23.9	25.1	24.7	26.9	26.4	27.8	27.2
146	24.0	23.9	25.5	25.3	27.2	27.1	28.2	28.1
151	25.8	25.5	26.7	25.9	28.2	27.5	29.9	29.2
153	26.6	25.9	28.2	27.9	30.1	28.8	32.0	30.6
158	25.7	25.7	27.8	26.9	28.0	27.2	29.6	28.6
160	25.0	24.8	27.0	26.3	28.4	28.2	30.4	29.8
165	26.7	26.7	28.5	28.1	30.2	29.8	32.2	32.0
167	26.2	26.1	28.4	28.0	30.1	29.8	32.2	31.7
172	27.8	27.5	29.2	22.4	31.1	30.1	33.2	32.5
174	28.3	28.0	29.8	29.2	31.6	30.9	33.5	33.3
179	29.1	29.0	30.4	29.6	32.5	32.4	33.7	33.7
181	28.9	28.7	30.7	30.0	32.0	31.7	34.0	33.8
186	29.0	28.7	30.7	30.1	32.2	32.0	33.9	33.6
188	30.2	29.9	31.3	30.7	32.7	32.5	34.5	34.2
193	29.3	29.3	31.9	31.7	33.0	32.9	32.2	32.1

(continued)

TABLE 3 (continued).

Day of Year	A		B		C		D	
	0.3 m	1.0 m	0.3 m	1.0 m	0.3 m	1.0 m	0.3 m	1.0 m
195	30.3	30.1	31.9	31.4	32.9	32.7	33.4	33.1
200	29.8	29.9	31.1	31.2	32.4	32.5	32.5	32.7
202	29.6	29.6	31.6	31.3	33.1	33.0	33.0	33.0
207	29.5	29.4	31.7	31.3	33.2	33.1	34.7	34.7
209	28.2	28.2	30.2	30.1	32.2	32.2	33.7	33.8
214	28.5	28.4	30.6	30.1	32.0	31.9	33.7	33.6
216	28.4	28.3	30.2	30.0	31.9	31.9	34.0	34.0
221	29.4	29.2	30.8	30.0	32.9	32.7	34.7	34.5
223	29.6	29.3	30.9	30.1	33.2	32.5	34.8	34.0
228	29.9	29.7	31.6	31.0	33.2	33.1	33.3	33.1
230	28.7	28.7	30.8	30.4	32.1	32.1	34.1	34.1
235	28.6	28.5	30.5	30.0	32.6	32.5	33.6	33.5
237	29.0	28.8	30.7	30.2	32.8	32.7	33.6	33.5
242	28.9	28.6	30.4	29.9	32.7	32.7	33.7	33.7
244	29.4	29.1	30.9	30.5	32.9	32.9	34.3	34.3

TABLE 4. REPRESENTATIVE MEAN DAILY SURFACE (0.3 m) AND BOTTOM (1.0 m) WATER TEMPERATURES IN THE LOWER SECTIONS OF THE EXPERIMENTAL CHANNELS, 1977 (A = AMBIENT, B = +2 C, C = +4 C, D = +6 C).

Day of Year	A		B		C		D	
	0.3 m	1.0 m	0.3 m	1.0 m	0.3 m	1.0 m	0.3 m	1.0 m
67	-	10.0	-	11.7	-	11.9	-	12.4
70	-	13.1	-	13.5	-	14.9	-	15.3
74	-	13.4	-	14.0	-	14.9	-	16.0
78	-	14.1	-	14.9	-	16.5	-	18.0
88	-	15.0	-	16.3	-	17.3	-	17.8
101	-	15.5	-	16.6	-	18.2	-	19.2
108	20.3	19.3	21.8	20.3	22.9	21.0	24.6	23.3
116	18.4	17.5	20.4	19.3	21.6	20.0	22.6	21.1
118	19.6	18.0	20.7	19.1	21.8	20.6	23.5	21.6
123	20.9	19.9	21.9	20.9	23.6	22.4	25.1	23.2
125	22.5	20.3	24.1	21.4	25.6	22.3	27.2	23.5
130	21.0	20.2	22.5	21.2	23.8	22.5	25.6	24.2
132	21.8	20.2	23.2	21.7	25.1	23.3	27.0	24.9
139	24.1	22.6	25.8	24.0	26.8	25.0	27.3	25.0
144	24.5	23.8	25.6	24.0	26.9	25.4	27.7	26.2
146	23.5	23.4	24.6	24.7	26.1	25.8	26.9	27.0
151	26.1	24.6	26.6	25.2	27.9	26.7	29.5	27.8
153	27.3	25.0	29.0	26.3	30.5	27.4	31.8	28.3
158	25.0	24.5	26.0	25.0	26.3	25.1	27.3	25.6
160	25.1	23.6	26.7	25.0	26.4	26.1	29.4	27.4
165	26.5	26.0	28.0	26.9	29.4	28.2	30.8	29.7
167	26.2	25.6	28.2	27.4	29.7	28.5	31.4	29.9
172	28.2	26.9	29.4	27.9	31.4	29.4	33.2	30.8
174	28.6	27.4	29.9	28.5	31.7	30.2	33.1	31.5
179	29.2	28.1	30.4	29.1	31.9	30.6	33.0	31.6
181	29.1	27.8	30.8	29.4	31.8	30.6	33.1	31.9
186	29.2	28.1	30.9	29.4	32.2	30.8	33.7	32.3
188	30.4	29.4	31.4	30.3	32.6	31.7	34.0	32.9
190	29.5	28.8	32.0	30.7	32.7	31.6	32.0	30.8

(continued)

TABLE 4 (continued).

Day of Year	A		B		C		D	
	0.3 m	1.0 m	0.3 m	1.0 m	0.3 m	1.0 m	0.3 m	1.0 m
195	30.8	29.7	32.1	30.9	33.4	32.3	33.4	32.3
200	29.2	29.2	30.5	30.7	31.5	31.5	32.2	32.3
202	29.8	29.0	31.6	30.7	32.7	31.9	32.4	31.8
207	29.5	29.0	31.1	31.4	32.7	31.9	33.9	32.4
209	27.7	27.6	29.2	28.8	30.7	30.2	31.7	31.4
214	28.5	27.5	30.3	29.3	31.6	30.7	33.0	32.1
216	28.2	27.7	29.6	29.0	31.0	30.6	32.2	31.5
221	29.5	28.5	30.9	29.0	32.6	31.3	34.2	32.9
223	29.7	28.6	31.0	29.8	32.7	31.5	34.1	32.9
228	30.2	29.1	31.8	30.3	32.9	31.9	32.2	30.9
230	28.6	28.0	30.4	29.6	31.4	30.7	33.1	32.6
235	28.4	27.6	30.3	29.0	32.2	31.2	33.0	32.1
237	29.2	28.2	30.7	29.5	32.4	31.4	33.0	32.2
242	29.0	27.8	30.4	29.1	32.3	31.3	32.9	32.0
244	29.6	28.5	31.0	29.8	32.5	31.6	33.7	32.9

TABLE 5. SUMMARY OF WATER QUALITY CONDITIONS IN BROWNS FERRY EXPERIMENTAL CHANNELS, MARCH TO AUGUST 1977.

	Ambient			+2 C			+4 C			+6 C		
	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.
Upper Section												
Dissolved Oxygen (PPM) @ 0.3 m	5.3	7.3	9.7	5.3	7.3	9.8	5.0	7.2	9.6	3.9	7.1	9.7
Dissolved Oxygen (PPM) @ 0.9 m	3.9	6.7	10.8	1.8	7.0	14.8	1.9	7.6	16.8	1.8	7.0	16.0
pH	6.6	7.4	7.9	6.6	7.5	8.2	6.6	7.4	7.8	6.6	7.4	7.8
Phenolphthalein Alkalanity (PPM)	0.0	0.0	0.0	0.0	0.05	0.5	0.0	0.0	0.0	0.0	0.0	0.0
Total Alkalinity ($CaCo_3$) (PPM)	29.5	45.3	5.2	31.0	46.0	51.5	31.0	45.5	51.5	31.0	45.7	51.5
Total Hardness ($CaCo_3$) (PPM)	23.1	55.5	64.6	23.1	55.5	64.6	23.5	55.2	64.1	24.4	55.4	64.6
Conductivity (Micromhos)	50.0	120.0	172.0	48.0	122.0	174.0	48.0	126.0	180.0	46.0	125.0	180.0
Secchi Disc (cm)	14.0	39.0	72.0	13.0	38.0	66.0	13.0	36.0	57.0	12.0	35.0	63.0
Nonfilterable Residue (PPM)	14.5	26.7	49.6	17.7	28.9	52.5	18.9	33.1	52.1	20.7	31.8	53.7
Underwater Light Photometer (% Transmittance) 0.3 m	7.2	33.1	39.0	6.4	30.3	48.0	3.4	30.0	52.0	10.0	27.9	46.0
0.6 m	0.6	11.9	26.0	0.4	9.2	16.0	0.6	10.2	20.0	0.5	9.6	18.0
0.9 m	0.04	4.0	10.0	0.02	3.0	7.0	0.02	3.3	7.0	0.05	3.1	6.3
Nitrate (PPM)	0.014	0.283	0.651	0.027	0.272	0.631	0.017	0.276	0.603	0.023	0.275	0.059
Nitrite (PPM)	0.007	0.014	0.032	0.005	0.014	0.032	0.005	0.014	0.032	0.005	0.014	0.033
Ammonia (PPM)	0.018	0.047	0.081	0.019	0.051	0.076	0.029	0.049	0.066	0.017	0.046	0.075

(continued)

TABLE 5 (continued).

	Ambient			+2 C			+4 C			+6 C		
	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.
Upper Section												
Organic Nitrogen (PPM)	0.10	0.20	0.27	0.12	0.18	0.20	0.13	0.19	0.26	0.13	0.19	0.25
Total Phosphate (PPM)	0.070	0.151	0.405	0.080	0.142	0.308	0.085	0.162	0.428	0.083	0.167	0.428
Ortho Phosphate (PPM)	0.029	0.062	0.097	0.032	0.062	0.097	0.029	0.066	0.097	0.034	0.066	0.103
Organic Carbon (PPM)	1.7	3.0	4.7	1.8	3.2	4.9	2.1	3.0	4.7	1.7	3.3	6.4
Biological Oxygen Demand (PPM)	0.8	1.2	1.6	0.3	1.1	1.8	1.1	1.4	1.9	0.7	1.5	2.1
Total Gas Saturation (%)	96	99	101	99	100	103	99	101	105	99	101	106
Saturation - N_2+A_r (%)	98	103	107	101	103	107	101	105	109	99	104	113
Lower Section												
Dissolved Oxygen (PPM) @ 0.3 m	6.1	8.2	10.4	5.8	8.5	10.6	6.0	9.1	13.2	6.6	9.7	13.0
Dissolved Oxygen (PPM) @ 0.9 m	3.8	8.1	16.5	3.9	7.8	15.3	3.9	9.1	>20.0	0.5	9.4	>20.0
pH	6.7	7.8	8.7	6.6	7.0	8.9	6.7	8.0	8.9	6.7	8.0	9.0
Phenolphthalein Alkalanity (PPM)	0.0	0.3	3.5	0.0	0.6	5.0	0.0	1.1	4.5	0.0	0.9	5.0
Total Alkalinity ($CaCo_3$) (PPM)	33.5	47.6	53.0	33.5	49.2	53.0	33.5	49.1	52.5	34.0	49.8	52.5
Total Hardness ($CaCo_3$) (PPM)	35.1	57.6	65.0	35.9	57.1	65.0	33.8	56.8	65.0	33.8	56.8	64.6

(continued)

TABLE 5 (continued).

	Ambient			+2 C			+4 C			+6 C		
	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.
Lower Section												
Conductivity (Micromhos)	72.0	125.0	176.0	72.0	126.0	176.0	70.0	127.0	176.0	70.0	129.0	180.0
Secchi Disc (cm)	13.0	68.0	122.0	13.0	64.5	122.0	13.0	66.0	122.0	13.0	61.0	96.0
Nonfilterable Residue (PPM)	3.4	12.9	33.7	6.6	15.0	37.4	3.5	14.0	37.4	3.2	14.8	39.0
Underwater Light Photometer (% Transmittance) 0.3 m	8.2	38.8	75.0	6.0	36.1	52.0	6.4	36.4	56.0	7.4	36.8	53.0
0.6 m	0.5	17.4	40.0	0.4	15.3	28.0	0.4	16.7	31.0	0.5	16.6	29.0
0.9 m	0.02	7.1	22.0	0.01	5.7	14.0	0.01	6.8	19.0	0.01	5.9	15.0
Nitrate (PPM)	0.020	0.264	0.620	0.010	0.260	0.618	0.009	0.259	0.601	0.023	0.263	0.599
Nitrite (PPM)	0.006	0.014	0.032	0.005	0.014	0.034	0.005	0.014	0.038	0.005	0.014	0.036
Ammonia (PPM)	0.015	0.045	0.070	0.017	0.036	0.062	0.005	0.036	0.061	0.005	0.032	0.072
Organic Nitrogen (PPM)	0.12	0.18	0.30	0.09	0.19	0.33	0.07	0.17	0.29	0.12	0.18	0.27
Total Phosphate (PPM)	0.053	0.131	0.310	0.550	0.128	0.321	0.050	0.117	0.246	0.053	0.120	0.305
Ortho Phosphate (PPM)	0.018	0.051	0.103	0.016	0.050	0.105	0.018	0.050	0.110	0.018	0.053	0.113
Organic Carbon (PPM)	1.8	3.2	7.0	1.8	3.4	8.0	1.1	3.0	6.4	0.8	2.8	4.6
Biological Oxygen Demand (PPM)	0.9	1.4	2.1	0.4	1.4	2.6	0.3	1.2	2.2	0.7	1.6	3.5
Total Gas Saturation (%)	96	100	106	98	101	107	99	101	108	99	102	109
Saturation - N_2+A_r (%)	89	101	105	88	100	106	85	98	106	80	96	105

SECTION 4

PRODUCTION AND BIOMASS OF BLUEGILL AND WALLEYE

INTRODUCTION

Evaluation of temperature requirements of bluegill and walleye is characterized by contrast. The bluegill is a widely distributed eurythermal species for which the field and laboratory thermal data base is essentially complete (Brungs and Jones, 1977). The corresponding data base for walleye, a coolwater species or temperate mesotherm (Hokanson, 1977), is less complete. Field observations have pertained primarily to spawning temperatures, and walleye have received only limited attention in the laboratory. The most definitive study on growth and survival in relation to temperature was done in the laboratory by Smith and Koenst (1975).

To some extent, upper tolerance limits for walleye growth and survival have been inferred on the basis of geographical distribution. Since walleye are more commonly associated with northern lakes and streams, a general assumption has been that walleye are excluded from most southern waters because of higher summer temperatures. However, in review of percid populations in the southeastern United States, Hackney and Holbrook (1978) reported that walleye distribution and abundance were relatively independent of temperature. Also, walleye have been stocked successfully in several Texas reservoirs (Prentice and Clark, 1978).

Although records of distribution have application in determining thermal requirements of a fish species, apparently the most sensitive function for establishing an upper temperature limit for long-term exposure is growth (NAS/NAE, 1973; Brungs and Jones, 1977). Since it has been practically impossible to assess growth in relation to temperature under field conditions, temperature requirements for growth have usually been determined in the laboratory (e.g. Brett *et al.*, 1969; McCormick and Kleiner, 1976), although there are exceptions (Bennett and Gibbons, 1974; Bisson and Davis, 1976). Utilizing large outdoor channels in which temperature treatments were replicated, the purpose of this phase of the study was to determine the effect of elevated temperature regimens on the growth of bluegill and walleye under simulated field conditions during the spring-summer season. Since the growth success of natural fish populations is usually measured on the basis of production and biomass, these parameters, which are a function of both growth and survival, were used to assess the experimental populations of bluegill and walleye in the channels.

Since walleye are more commonly associated with other prey species (e.g. yellow perch), walleye-bluegill could be considered an unlikely predator-prey combination; however, it has been reported that walleye will forage on bluegill and other lepomids (Dendy, 1946; Forney, 1966; Schneider, 1975). Also, in our preliminary studies under ambient temperature conditions in the channels, juvenile walleye readily utilized young-of-the-year bluegill (Forsythe and Wrenn, 1978).

MATERIALS AND METHODS

Bluegill and walleye for this study were obtained from the Carbon Hill National Hatchery (Alabama). Age I bluegill (spawned in late summer 1976) were from a stock maintained at this hatchery, where the water temperature normally ranges from 5° C in the winter to 32° C in the summer. The walleye were obtained initially as sac-fry from Senecaville National Hatchery (Ohio) and reared for a month at Carbon Hill; origin of the broodstock was Linesville, Pennsylvania. Bluegill (mean TL 70 mm; mean weight 5 g) were stocked in the channels on 3 March 1977, and walleye (mean TL 42 mm; mean weight 0.5 g) were stocked on 13 May 1977. Although the mean weight of the bluegill was only 5 g, previous experience showed that they would be large enough (ca. 30 g) to spawn in May. Also, Regier (1963) noted that differences in the size of bluegill in the fall did not affect the probability that they would spawn at Age I the following spring. Young-of-the-year (YOY) bluegill were expected to provide the forage base for the walleye. Although the bluegill were stocked on 3 March, temperature treatments were not established until 8 March. Bluegill were stocked 150 (3,125/ha) per channel or 60 and 90 in the upper and lower sections, respectively. Walleye numbers stocked in the upper and lower sections of divided channels were 12 (632/ha) and 20 (690/ha), respectively. The undivided channel in each treatment (regimen) received 32 walleye (667/ha). Stocking densities for bluegill and walleye were derived, on the basis of maximum walleye growth and survival, from previous evaluation of stocking rates under ambient temperature conditions in the channels (Forsythe, 1978). At stocking, the bluegill in each population were weighed and measured individually, whereas mean length and weight of walleye were derived from a composite sample. With one undivided and two divided channels in each of the four temperature regimens, a total of 20 bluegill-walleye populations were stocked.

To determine growth, each population was sampled monthly by electrofishing (pulsed DC; 20 cycles/sec; 150 V AC input; output ca. 2 amperes). Sample sizes were 10 to 30% of the walleye population and 10% of the bluegill. Decreases in population numbers were estimated from daily visual inspection of the channels for dead fish. After 185 days (118 days for the walleye) the channels were drawn down partially, and the adult bluegill, walleye, and YOY bluegill were recovered with rotenone. Although precise limits for the fish growing season are not available for this region, we assume that the interval of this study covered approximately 90 percent of the growth season, and therefore, would be representative of the annual growth or production. Jones *et al.* (1977) reported that over 90% of the fish production (seven species, including bluegill and largemouth bass) in a Texas pond (similar latitude to northern Alabama) occurred from June through September.

Production in this study is defined as the total incremental growth of fish tissue throughout the duration of the study, including that formed by individuals which did not survive to the end of the experiment (Ivlev, 1966 as cited by Chapman, 1971). Production (as wet weight) of the adult bluegill and walleye was estimated numerically according to the Ricker formula (1946), on the basis of six monthly sampling intervals for bluegill, four for the walleye, between 8 March and 9 September. For each sampling interval, production was calculated as:

$$P = G\,\overline{B}$$

where P is production in kg, G is the instantaneous rate of increase in weight, and $\overline{B}$ is the mean biomass of the population. Exponential models of growth and mortality were applied to the calculations of G and $\overline{B}$ (Chapman, 1971). For the adult bluegill, estimates of mean individual weights and population numbers were used in the calculation of production for the frist five intervals, and actual mean weights and numbers of bluegill recovered by rotenone were used for the last interval. For the walleye, estimates of mean weight and population numbers were used for the first three intervals (months), and actual mean weights and numbers were used for the fourth production interval.

Production (as wet weight) of YOY bluegill in the upper channel sections of the four temperature regimens was also estimated. These estimates were calculated by the graphical or Allen method (Chapman, 1971) on the basis of (1) estimated total numbers of larvae hatched, (2) an intermediate estimate of larval densities and mean weights, and (3) total numbers and mean weights of YOY bluegill recovered by rotenone.

The biomass of each population was calculated as the difference between the biomass of the population stocked and the biomass of the population recovered at the end of 185 days for the bluegill and 118 days for the walleye. Biomass of YOY bluegill was the biomass recovered by rotenone at the end of the study.

BLUEGILL

Total production of adult (Age I) bluegill in the upper channel sections for the four temperature treatments ranged from 20 g/m^2 in the ambient regimen to 15 g/m^2 in the +6 C regimen (Table 6). The highest monthly production for adults occurred in all treatments during 11 April to 10 May when production ranged from 6.7 g/m^2 in the +2 C regimen to 5.1 g/m^2 in the +4 C regimen. This period preceded the onset of spawning in all treatments except in the +6 C channels (see Section 5). Combined production of adult and YOY bluegill in the upper sections ranged from 99 g/m^2 (999 kg/ha) in the +6 C regimen to 75 g/m^2 (752 kg/ha) in the +2 C regimen (Table 7). Population numbers and mean weights of YOY bluegill used to establish the Allen production curves for the upper sections are presented in Table 8. Ratios of production (adult plus YOY) to biomass were as follows: ambient - 1.9:1, +2 C - 1.9:1, +4 C - 2.1:1, and +6 C - 2.4:1.

TABLE 6. MEAN PRODUCTION STATISTICS OF BLUEGILL IN EXPERIMENTAL CHANNELS. WATER TEMPERATURES IN CHANNELS WERE AMBIENT (WHEELER RESERVOIR, TENNESSEE RIVER), OR ELEVATED +2 C, +4 C, +6 C ABOVE AMBIENT IN THE UPPER CHANNEL SECTIONS. WITHIN EACH TEMPERATURE REGIMEN, TWO CHANNELS WERE DIVIDED INTO UPPER (ISOTHERMAL) AND LOWER (COOLING) SECTIONS, AND ONE CHANNEL WAS UNDIVIDED.

Time Interval	Individual Size (g)				Instantaneous Growth Rate				Population Numbers[a]				Biomass (g)				Production (g/m^2)			
	A	+2C	+4C	+6C	A	+2C	+4C	+6C	A	+2C	+4C	+6C	A	+2C	+4C	+6C	A	+2C	+4C	+6C
UPPER SECTION																				
8 Mar	6	5	7	5					60	60	60	60								
8 Mar-10 Apr	13	13	21	18	0.72	0.83	1.02	1.04	60	60	60	60	540	540	825	705	2.05	2.36	4.43	3.86
11 Apr-10 May	26	28	32	29	0.73	0.76	0.42	0.49	60	60	59	59	1,155	1,159	1,565	1,365	4.44	4.64	3.46	3.52
11 May- 8 Jun	44	48	48	47	0.54	0.58	0.42	0.50	59	59	59	58	2,046	2,211	2,325	2,208	5.81	6.75	5.14	5.81
9 Jun-10 Jul	63	63	57	57	0.34	0.25	0.16	0.17	58	58	59	58	3,112	3,250	3,083	3,005	5.57	4.28	2.60	2.69
11 Jul- 8 Aug	69	64	60	54	0.10	0.02	0.05	-0.12	57	58	59	56	3,802	3,723	3,421	3,144	2.00	0.39	0.90	-1.98
9 Aug- 8 Sept	70	62	58	57	0.02	-0.03	-0.03	0.06	58	52	57	55	4,002	3,450	3,408	3,046	0.42	-0.54	-0.54	0.96
Total[b]																	20	18	16	15

[a] Mean of 2 replicates in upper and lower sections rounded to whole fish.

[b] Production value rounded to nearest gram.

(continued)

TABLE 6 (continued).

Time Interval	Individual Size (g)				Instantaneous Growth Rate				Population Numbers[a]				Biomass (g)				Production (g/m^2)			
	A	+2C	+4C	+6C	A	+2C	+4C	+6C	A	+2C	+4C	+6C	A	+2C	+4C	+6C	A	+2C	+4C	+6C
LOWER SECTION																				
8 Mar	6	5	6	5					90	90	90	90								
8 Mar-10 Apr	13	17	21	19	0.76	1.04	1.18	1.15	90	90	90	90	838	968	1,193	1,058	2.20	3.47	4.85	4.19
11 Apr-10 May	29	27	33	29	0.80	0.50	0.44	0.43	89	89	89	89	1,783	1,932	2,363	2,064	4.92	3.33	3.58	3.06
11 May- 8 Jun	47	53	52	53	0.48	0.69	0.49	0.64	89	89	88	88	3,321	3,474	3,734	3,516	5.50	8.27	6.31	7.76
9 Jun-10 Jul	64	59	57	57	0.24	0.11	0.09	0.07	83	88	87	88	4,491	4,959	4,767	4,823	3.72	1.88	1.48	1.16
11 Jul- 8 Aug	63	61	52	56	0.09	0.03	-0.09	-0.01	79	88	86	88	5,076	5,287	4,704	4,963	1.57	0.64	-1.46	-0.17
9 Aug- 8 Sept	66	62	55	56	0.01	0.01	0.06	0.001	69	81	79	80	4,878	4,992	4,408	4,700	0.17	0.17	0.15	0.02
Total[b]																	18	18	15	16
UNDIVIDED																				
8 Mar	5	6	6	5					150	150	150	150								

[a] Mean of 2 replicates in upper and lower sections rounded to whole fish.

[b] Production value rounded to nearest gram.

(continued)

TABLE 6 (continued).

Time Interval	Individual Size (g)				Instantaneous Growth Rate				Population Numbers[a]				Biomass (g)				Production (g/m^2)			
	A	+2C	+4C	+6C	A	+2C	+4C	+6C	A	+2C	+4C	+6C	A	+2C	+4C	+6C	A	+2C	+4C	+6C
UNDIVIDED (continued)																				
8 Mar-10 Apr	13	15	20	20	0.84	0.81	1.06	1.22	150	150	150	150	1,350	1,575	1,950	1,875	2.36	4.40	4.31	4.77
11 Apr-10 May	33	43	34	36	0.93	1.05	0.53	0.59	149	149	149	149	3,208	3,972	3,943	4,068	6.22	8.69	4.35	5.00
11 May- 8 Jun	55	55	55	53	0.53	0.25	0.50	0.40	147	148	149	149	6,430	7,270	6,564	6,596	7.09	3.79	6.84	5.50
9 Jun-10 Jul	56	62	62	68	0.02	0.11	0.11	0.23	145	145	149	149	8,101	8,531	8,717	9,015	0.34	1.96	2.00	4.32
11 Jul- 8 Aug	60	61	55	63	0.07	-0.02	-0.12	-0.08	141	144	148	147	8,289	8,886	8,677	9,690	1.21	-0.37	-0.36	-1.62
9 Aug- 8 Sept	60	60	57	60	0	-0.02	0.04	-0.05	118	138	128	132	7,750	8,530	7,710	8,573	0	-0.36	-0.32	-0.89
Total																	17	18	17	17

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[a] Mean of 2 replicates in upper and lower sections rounded to whole fish.

[b] Production value rounded to nearest gram.

TABLE 7. PRODUCTION AND BIOMASS OF ADULT AND YOUNG-OF-THE-YEAR (YOY) BLUEGILL IN UPPER SECTIONS OF EXPERIMENTAL CHANNELS (MARCH-SEPTEMBER). WATER TEMPERATURES WERE AMBIENT (WHEELER RESERVOIR, TENNESSEE RIVER) OR ELEVATED +2 C, +4 C, and +6 C ABOVE AMBIENT.

Temperature Regimen	Production,[1] kg/ha				Biomass,[1] kg/ha			
	Adult[2]	YOY	Total	% YOY	Adult	YOY	Total	% YOY
Ambient	200	687	887	77	195	270	465	58
+2 C	178	574	752	76	155	224	378	59
+4 C	177	632	809	78	155	216	371	58
+6 C	159	840	999	84	144	269	413	65

[1] Mean of two replicates.

[2] Age I bluegill stocked in channels in March.

TABLE 8. EXAMPLES OF POPULATION SIZES (IN THOUSANDS) AND MEAN WEIGHTS (G) OF YOUNG-OF-THE-YEAR BLUEGILL USED TO PLOT ALLEN PRODUCTION CURVES FOR UPPER CHANNEL SECTIONS.

Temperature Regimen	Bluegill larvae hatched[a]		Intermediate population[b]		YOY bluegill recovered	
	No.	Wt.	No.	Wt.	No.	Wt.
Ambient	343	-	20	0.03	9.4	0.55
+2 C	355	-	20	0.03	11.6	0.36
+4 C	485	-	20	0.03	13.0	0.31
+6 C	500	-	20	0.03	8.3	0.61

[a] Calculated on basis of number of nests with eggs and 5,000 larvae per nest; mean weight plotted as zero.

[b] Peak density of post larvae as determined from net tows.

Biomass of adult bluegill in the upper channel sections ranged from 195 kg/ha in the ambient channels to 144 kg/ha in the +6 C regimen, while biomass in both the intermediate treatments (+2 C and +4 C) was 155 kg/ha (Table 9). Mean biomass of adults between treatments in the upper sections was significantly different but there was not significant linear regression (analysis of variance with regression, $P \leq 0.05$). However, the total biomass of adult plus YOY bluegill in the upper sections, which ranged from 465 kg/ha at ambient to 371 kg/ha in the +4 C regimen (Table 7), was not significantly different between treatments (analysis of variance, $P \leq 0.05$).

In the lower sections of the two divided channels within each treatment, mean biomass of adult bluegill, which ranged from 144 kg/ha in the +2 C regimen to 132 kg/ha in the +4 C regimen, was not significantly different between temperature regimens ($P \leq 0.05$). However, while the biomass of YOY bluegill and the total biomass were significantly different, there was no apparent relation to temperature since biomass was lowest in the +4 C and +2 C regimens with 256 and 278 kg/ha, respectively. The biomass of both adult and YOY bluegill in the upper sections was significantly higher than that in the lower sections of the divided channels (*t*-test, $P \leq 0.05$).

Biomass of adult bluegill in the undivided channels (one channel per treatment) ranged from 156 kg/ha in the +2 C regimen to 131 kg/ha in the ambient regimen. Total biomass of adults plus YOY ranged from 260 kg/ha in the +4 C regimen to 364 kg/ha in the +6 C regimen.

Temperature treatments had no apparent effect on survival of adults. Mean survival of the adult bluegill in the upper sections ranged from 97% in the ambient regimen to 88% in the +2 C regimen after 185 days (Table 9). While in the lower sections, survival ranged from 89% in the +6 C regimen to 77% in the ambient channels, and survival in the undivided channels ranged from 92% in the +2 C regimen to 79% in the ambient channel. The lower survival rate of bluegill in the lower sections and undivided channel of the ambient regimen was attributed to an outbreak of gill lice (*Ergasilus* sp.). From the observed mortalities and the numbers of bluegill recovered by rotenone at termination of the study, the mean percent of recovery of the original adult stocks for the 20 populations was 92.2% (range 84 to 100%).

Mean individual weight gain of bluegill (sexes combined) surviving for the duration of the test ranged from 64 g in the ambient regimen (upper section) to 49 g in the lower sections of the +4 C regimen; the specific growth rates (%/day) were 1.32 and 1.19, respectively (Table 9). Males were larger than females; at termination of the study, mean weight of males and females was 68 g and 51 g, respectively. Also, mean weight of females (62 g) in the ambient regimen (upper section) was significantly higher than the mean weight for females in the elevated regimens (*t*-test, $P \leq 0.05$). Mean weight of males between treatments was not significantly different. Male to female sex ratios of the bluegill recovered at the end of the experiment were as follows: 1:1.2 (ambient), 1.3:1 (+2 C), 1:1 (+4 C), and 1.1:1 (+6 C). The initial sex ratio (M:F) for all populations was 1:1.1, as determined by dissecting a sample (57) of the composite stock upon arrival from the hatchery.

TABLE 9. MEAN GROWTH, SURVIVAL, AND BIOMASS OF AGE I BLUEGILL IN 12 EXPERIMENTAL CHANNELS FOR 185 DAYS (MARCH-SEPT.). WATER TEMPERATURES IN CHANNELS WERE AMBIENT (WHEELER RESERVOIR, TENNESSEE RIVER) OR ELEVATED +2 C, +4 C, OR +6 C ABOVE AMBIENT IN THE UPPER CHANNEL SECTIONS. WITHIN EACH TEMPERATURE REGIMEN, TWO CHANNELS WERE DIVIDED INTO UPPER (ISOTHERMAL) AND LOWER (COOLING) SECTIONS, AND ONE CHANNEL WAS UNDIVIDED.

Parameter	Upper Section				Lower Section				Undivided			
	A	+2C	+4C	+6C	A	+2C	+4C	+6C	A	+2C	+4C	+6C
Length increase (mm)	77	70	65	67	74	70	65	68	68	69	70	72
Weight increase (g)	64	57	51	52	61	57	49	51	55	54	51	55
Specific growth rate (wt.) (%/day)	1.32	1.36	1.14	1.31	1.39	1.36	1.19	1.30	1.34	1.24	1.21	1.34
Specific mortality rate (%/day)	0.02	0.07	0.02	0.05	0.14	0.09	0.07	0.06	0.12	0.04	0.08	0.07
Survival %	97	88	96	91	77	84	88	89	79	92	85	88
Yield (kg/hectare) (± 1 SD)	195 (2.8)	155 (17.6)	155 (7.1)	144 (14.1)	141 (17.7)	144 (8.5)	132 (1.4)	140 (2.8)	131 -	156 -	136 -	150 -

WALLEYE

After 118 days, mean biomass of walleye from the upper channel sections ranged from 36 kg/ha in the ambient regimen to 0 kg/ha in the highest regimen (+6 C), in which none of the walleye survived to the end of the test (Table 10). Ambient temperature conditions exceeded 28° C for 78 days, and the maximum was 30° C for about 5 days (Fig. 2, Section 3). Biomass from the upper sections of the intermediate temperature regimens, +2 C and +4 C, decreased to 28 and 18 kg/ha, respectively. With the exception of the +6 C regimen, the mean biomass between treatments in the upper sections were not significantly different but the decline in biomass was significant (analysis of variance with regression $P \leq 0.05$). Also, there were no significant differences in biomass between treatments for the lower sections. With the exception of the +6 C treatment, there were no significant differences in biomass from upper and lower sections within treatments. Biomass from the undivided channels, similar to that for the lower sections, ranged from 26 kg/ha in the +2 C and +4 C regimens to 20 kg/ha in the +6 C regimen. Maximum temperatures at which walleye survived and continued to grow (Table 11) were 32-33° C which occurred for about 75 days in the upper sections of the +4 C regimen; similar thermal conditions also occurred in the lower sections of the +6 C regimen.

Production estimates followed the same trend as that for biomass in the upper sections in that production was highest (5.5 g/m^2) in the ambient temperature regimen, intermediate (3.9 g/m^2) in the +4 C regimen, and lowest (2.8 g/m^2) in the +6 C regimen (Table 11). In the lower sections and undivided channels, production was not indicative of biomass in every case, e.g. production in the undivided channels was highest in the ambient regimen (5.1 g/m^2 or 51 kg/ha), but the biomass (21 kg/ha) was next to the lowest for the four temperature regimens.

Production at the end of the first month (13 May-8 June) was progressively higher in the elevated temperature regimens (Table 11). In the upper sections, production in the +6 C regimen was 1.1 g/m^2 or more than twice that from the ambient regimen (0.4 g/m^2). However, at the end of the third month (8 August), production estimates for the ambient regimen (upper section) (2.3 g/m^2) exceeded that in the +6 C regimen by 1.4 g/m^2. Any change in production for the +6 C treatment (upper section) after 8 August was not accounted for since no walleye were recovered from this treatment at the end of the test. Walleye production was also greater initially in the other elevated temperature regimens, but production in the ambient channels eventually equaled or exceeded this early gain.

Based on the actual numbers of walleye recovered after 118 days, survival in all treatments was overestimated (Table 11) for the first three production intervals which would cause production to be overestimated also. Although we believe that the unaccounted mortalities (or possibly escapement) occurred when the walleye were very small (40-50 mm, TL), no attempt was made to distribute these missing fish in estimating production. Unaccounted fish were essentially the same among treatments.

TABLE 10. MEAN GROWTH, SURVIVAL, AND BIOMASS OF WALLEYE IN 12 EXPERIMENTAL CHANNELS FOR 118 DAYS (MAY-SEPT.). WATER TEMPERATURES IN CHANNELS WERE AMBIENT (WHEELER RESERVOIR, TENNESSEE RIVER) OR ELEVATED +2 C, +4 C, or +6 C ABOVE AMBIENT IN THE UPPER CHANNEL SECTIONS. WITHIN EACH TEMPERATURE REGIMEN, TWO CHANNELS WERE DIVIDED INTO UPPER (ISOTHERMAL) AND LOWER (COOLING) SECTIONS, AND ONE CHANNEL WAS UNDIVIDED.

Parameter	Upper Section				Lower Section				Undivided			
	A	+2C	+4C	+6C	A	+2C	+4C	+6C	A	+2C	+4C	+6C
Length increase[a] (mm)	175	175	141	147[b]	178	167	153	146	168	162	151	132
Weight increase (g)	90	88	61	-	88	77	66	65	78	70	68	57
Specific growth rate (wt.) (%/day)	4.40	4.37	4.07	-[c]	4.38	4.27	4.14	4.13	4.27	4.18	4.16	4.01
Specific mortality rate (%/day)	0.41	0.52	0.66	-	0.63	0.54	0.63	0.59	0.76	0.49	0.49	0.54
Survival (%)	63	54	46	0	48	53	48	50	41	56	56	53
Yield (kg/hectare) (± 1 SD)	36 (8.4)	29 (11.3)	18 (6.6)	0 -	25 (2.9)	28 (2.8)	21 (1.6)	22 (0.6)	21 -	26 -	26 -	20 -

[a] Initial mean length (TL) - 42 mm; mean wt. - 0.5 g.

[b] Mean length (TL) of 3 dead walleye recovered in mid-August.

[c] Not computed, no walleye surviving at end of test.

TABLE 11. MEAN PRODUCTION STATISTICS OF WALLEYE IN EXPERIMENTAL CHANNELS. WATER TEMPERATURES IN CHANNELS WERE AMBIENT (WHEELER RESERVOIR, TENNESSEE RIVER) OR ELEVATED +2 C, +4 C, +6 C ABOVE AMBIENT IN THE UPPER CHANNEL SECTIONS. WITHIN EACH TEMPERATURE REGIMEN, TWO CHANNELS WERE DIVIDED INTO UPPER (ISOTHERMAL) AND LOWER (COOLING SECTIONS, AND ONE CHANNEL WAS UNDIVIDED.

Time Interval	Individual Size (g)				Instantaneous Growth Rate				Population Numbers[a]				Biomass (g)				Production (g/m^2)			
	A	+2C	+4C	+6C	A	+2C	+4C	+6C	A	+2C	+4C	+6C	A	+2C	+4C	+6C	A	+2C	+4C	+6C
UPPER SECTION																				
13 May	0.5	0.5	0.5	0.5					12	12	12	12								
13 May-8 Jun	5	9	10	12	2.66	3.25	3.38	3.66	12	12	12	11	30	46	51	61	0.42	0.79	0.91	1.17
9 Jun-10 Jul	24	34	26	24	1.47	1.31	0.92	0.63	12	12	12	11	174	255	210	204	1.35	1.76	1.02	0.68
11 Jul-8 Aug	62	58	53	42	0.95	0.52	0.73	0.56	12	12	11	10	479	544	439	337	2.39	1.49	1.68	0.99
9 Aug-8 Sept	91	87	62	0	0.38	0.42	0.15	0	7	7	6	0	708	610	454	0	1.42	1.35	0.36	0
Total																	5.58	5.38	3.96	2.84
LOWER SECTION																				
13 May	0.5	0.5	0.5	0.5					20	20	20	20								
13 May-8 Jun	5	9	8	13	2.66	3.27	3.10	3.71	20	20	20	20	50	77	70	108	0.46	0.87	0.75	1.38
9 Jun-10 Jul	28	32	26	35	1.57	1.23	1.14	0.95	20	20	19	19	330	400	323	463	1.79	2.17	1.27	1.52

[a] Mean of 2 replicates in upper and lower sections rounded to whole fish.

(continued)

TABLE 11 (continued).

Time Interval	Individual Size (g)				Instantaneous Growth Rate				Population Numbers[a]				Biomass (g)				Production (g/m²)			
	A	+2C	+4C	+6C	A	+2C	+4C	+6C	A	+2C	+4C	+6C	A	+2C	+4C	+6C	A	+2C	+4C	+6C
LOWER SECTION, Continued																				
11 Jul-8 Aug	61	58	41	59	0.81	0.61	0.48	0.54	20	20	19	19	858	869	633	890	2.40	1.83	1.05	1.66
9 Aug-8 Sept	82	77	60	65	0.28	0.28	0.38	0.10	10	11	10	10	951	974	677	857	0.92	0.94	0.89	0.30
Total																	5.57	5.34	3.95	4.87
UNDIVIDED																				
13 May	0.5	0.5	0.5	0.5					32	32	32	32								
13 May-8 Jun	7	7	13	14	3.05	3.05	3.76	3.84	32	32	32	32	105	105	178	190	0.66	0.66	1.40	1.53
9 Jun-10 Jul	28	27	32	36	1.30	1.27	0.84	0.89	32	32	31	31	560	544	704	782	1.52	1.43	1.24	1.44
11 Jul-8 Aug	59	57	40	58	0.75	0.75	0.22	0.48	32	32	31	29	1,392	1,285	1,111	1,380	2.16	2.00	0.52	1.37
9 Aug-8 Sept	78	70	68	57	0.28	0.21	0.53	-0.02	13	18	18	17	1,406	1,525	1,231	1,292	0.82	0.65	1.36	-0.05
Total																	5.16	4.75	4.51	4.29

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[a] Mean of 2 replicates in upper and lower sections rounded to whole fish.

Mean survival of walleye after 118 days ranged from 63% in the upper sections of the ambient regimen to no survival in the upper sections of the +6 C regimen (Table 10). The last observed mortality in the +6 C regimen was 15 August; four additional mortalities occurred in this treatment from 22 July to 15 August. No moribund or distressed walleye were observed prior to the finding of dead specimens. Average minimum temperatures during this interval ranged from 33.6° to 34.7° C. Mean survival for the five walleye populations in the ambient regimen was 50%, essentially the same as that (52%) in all elevated regimens, except the +6 C treatment. Mean individual weight gain of walleye surviving for the duration of this test ranged from 91 g in the ambient regimens (upper sections) to 57 g in the undivided channels at the +6 C regimen, while the respective specific growth rates (%/day) ranged from 4.40 to 4.01 (Table 10).

DISCUSSION

Maximum elevated temperatures, which ranged from ca. 31° to 34° C for more than 70 days in the upper channel sections, had no significant effect on production and biomass of the experimental bluegill populations in this study. Although production and biomass of the adult stocks were less in the elevated treatments, there were compensatory increases in production and biomass by YOY bluegill (Table 7). Production, which ranged from 999 kg/ha in the +6 C regimen to 752 kg/ha in the +2 C regimen, was greater than the revised estimate of bluegill production (625 kg/ha) in a thermally unaltered lake (Gerking, 1962; Mahon, 1977). The high YOY production (840 kg/ha) in the +6 C channels resulted from the earlier onset of spawning (by a month) which yielded a greater total number of spawns, 3.3 per female as opposed to 2.5 per female in the ambient channels (see Section 5). Since the eggs may comprise up to 13% of the total biomass of female bluegill (Toetz, 1967), the longer spawning season was considered to be a factor in reducing adult production in the +6 C treatment (159 kg/ha vs. 200 kg/ha in the ambient channels). Biomass from the elevated temperature regimens (e.g. 413 kg/ha in the +6 C regimen) was comparable to the relatively high standing stocks associated with bass-bluegill ponds (Swingle, 1950).

In general, the effect of temperature on bluegill in the present study was similar to results obtained in the laboratory. Lemke (1977) reported that maximum bluegill growth over a 30-day interval was highest at 30° C but that growth was not significantly different at temperatures ranging from 22° to 34° C. Also, adult and YOY bluegill tolerated temperatures that approached 35° C in the highest regimen (+6 C), which is within the tolerance limit reported by Stauffer *et al.* (1976). The survival rate was 0.91 in the +6 C regimen which was considered to be comparable to the 0.70 survival of Age II bluegill (1 May-1 Nov.) in a natural population (Ricker, 1945).

The ambient temperature regimen in the channels, typical of summer temperatures in mainstream reservoirs of the Tennessee River, had no apparent adverse effect on the biomass of experimental populations of juvenile walleye. Carlander (1977) reported that the biomass of walleye in three lakes under 100 hectares averaged 26.8 kg/ha; mean biomass of walleye in 23 North American lakes was 16 kg/ha. Mean biomass of the five walleye populations held at ambient temperatures in the channels was 28 kg/ha. Mean individual growth (total length > 200 mm) in the ambient regimen was equal to the rapid growth reported for walleye in Norris Reservoir and other southeastern waters (Stroud, 1949; Hackney and Holbrook, 1978). The mean specific mortality rate (0.60%/day) was within the range of natural mortality rates determined for juvenile walleye in Oneida Lake (Forney, 1971). In general, the survival and growth of walleye in the ambient regimen were comparable to the results obtained with walleye in Texas reservoirs (Prentice, 1977; Prentice and Dean, 1977; Prentice and Clark, 1978). Their results showed that survival, growth and harvest of stocked walleye could be expected in almost all Texas reservoirs, where growth of Age I walleye ranged from 267-454 mm. Mid-summer temperatures in these reservoirs generally ranged from 27-30° C (J. A. Prentice, personal communication). The significant relationship to temperature was that self-sustaining walleye populations could not be maintained if temperatures during the spawning season exceeded 12° C.

The upper channel sections of the elevated temperature regimens were considered to simulate conditions that would occur if the temperature increased in an entire water body such that cooler refuge areas would not be available to the walleye. After 118 days, mean individual size of walleye in the +2 C and +4 C regimens was less than that for walleye in the ambient regimen, and no walleye survived to the end of the test in the +6 C regimen (Table 10). Obviously, the total mortality in the +6 C regimen was ecologically significant; however, the significance of the reduced size of walleye in the +4 C regimen was not clear since the size attained by walleye in this treatment was not abnormal (mean TL 183 mm and weight 62 g). Under conditions similar to those in the channels (abundant forage and no competing fishes), Walker and Applegate (1976) reported that walleye attained a mean length of 167 mm and weight of 41 g in a 12.5 hectare pothole in South Dakota (13 June-13 September).

Effects of temperature on walleye growth and survival in the upper sections contrasted to results obtained by Smith and Koenst (1975) under laboratory conditions. They reported that the optimum temperature for growth of juvenile walleye in a 28-day experiment was 22° C and that the incipient lethal temperature (50% mortality) was 31.6° C; the temperature for zero net growth was 29° C as extrapolated by Hokanson (1977). Ambient temperatures in the channels were near or above 29° C for the last 75 days of the experiment and the average minimum temperature in the +4 C regimen exceeded 29° C for 95 days. According to the interval production statistics (Table 11), walleye in both the ambient and +4 C regimen were growing during these periods. The upper lethal temperature for walleye in the channels (+6 C regimen, upper section) was about 34° C although this was not determined on the basis of 50% mortality. Differences in the results between the laboratory and channel studies probably were due to the lower acclimation temperature (26° C) and the direct transfer technique in handling the fish that were employed in the laboratory study (Hokanson, 1977).

Thermal conditions in the undivided channels were considered to simulate thermal plumes such as those associated with heated discharges from power plants. In this case, the highest temperature in the plume would occur in 40% of the mixed water body (channel), but the walleye were not prevented from seeking cooler zones along a thermal gradient or vice versa. Although the mean size of walleye attained after 118 days in the elevated regimens was less (8 to 21 g) than that in the ambient channel, the biomass which reflected both growth and survival was about equal to or higher than that in the undivided ambient channel (Table 10). Apparently, the thermoregulatory behavior of walleye (Ferguson, 1958; Hokanson, 1977) enabled the population in the undivided channel of the +6 C regimen to avoid the lethal temperatures (ca. 34° C) for walleye confined to the upper channel sections in this treatment. Average minimum temperatures in the lower section of the +6 C regimen ranged from 32° to 33° C during the period (22 July-15 August) when lethal conditions were apparently reached in the upper section. Based on the interval production statistics between 10 July and 8 August (Table 11), growth occurred during this interval in both the lower divided sections and the undivided channel in the +6 C regimen.

Although the juvenile stage is perhaps the most thermally tolerant stage in the life cycle of percids, with walleye being the least tolerant (Hokanson, 1977), results from the present channel experiment indicated that walleye were more thermally tolerant than previously considered. Thermal tolerance of walleye in this study was more similar to that determined for young yellow perch (*Perca flavescens*) (McCormick, 1976). Although there may be differences in the thermal tolerance of different genetic strains, there was no intent to test this hypothesis although a northern stock of walleye was used in the present study. However, the experimental channels would be appropriate for evaluating different geographical or genetic stocks of walleye.

REFERENCES

Bennett, D. H. and J. W. Gibbons. 1974. Growth and condition of juvenile largemouth bass from a reservoir receiving thermal effluents. *In* Thermal Ecology, J. W. Gibbons and R. R. Sharitz (Eds.), AEC Symposium Ser. (CONF-730505). pp. 246-254.

Bisson, P. A. and G. E. Davis. 1976. Production of juvenile chinook salmon, *Oncorhynchys tshawygtscha*, in a heated model stream. Fishery Bulletin, 74(4): 763-774.

Brett, J. R., J. E. Shelbourn, and C. T. Shoop. 1969. Growth rate and body composition of fingerling sockeye salmon, *Oncorhynchus nerka*, in relation to temperature and ration size. J. Fish. Res. Board Can. 26: 2363-2394.

Brungs, W. A. and B. R. Jones. 1977. Temperature criteria for freshwater fish: protocol and procedures. U.S. Environ. Prot. Agency, Duluth, MN. EPA-600/3-77-061. 130 pp.

Carlander, K. D. 1977. Biomass, production, and yields of walleye (*Stizostedion vitreum vitreum*) and yellow perch (*Perca flavescens*) in North American lakes. J. Fish. Res. Board Can. 34(10): 1602-1612.

Chapman, D. W. 1971. Production. Pages 199-214. *In* W. E. Ricker, ed. Methods for assessment of fish production in freshwaters. IBP Handbook No. 3, 2nd ed., Blackwell, Oxford, and Edinburg.

Forney, J. L. 1966. Factors affecting first-year growth of walleyes in Oneida Lake, New York. New York Fish and Game Jour. 13(2): 146-167.

Forney, J. L. 1971. Analysis of year class formation in a walleye population. Federal Aid Project F-17-R, Rep. Job I-a, N.Y. State Dept. Environ. Conserv.

Forsythe, T. D. 1978. Predator-prey interactions among crustacean plankton, young bluegill (*Lepomis macrochirus*), and walleye (*Stizostedion vitreum vitreum*) in experimental ecosystems. Ph.D. Thesis, Mich. State Univ., East Lansing. 98 pp.

Forsythe, T. D. and W. B. Wrenn. 1978. Predator-prey relationships among walleye and bluegill in experimental ecosystems. *In* H. Clepper, ed. An International Symposium on Predator-Prey Systems in Fish Communities and Their Role in Fisheries Management (in press).

Gerking, S. D. 1962. Production and food utilization in a population of bluegill sunfish. Ecol. Monogr. 32: 31-78.

Hackney, P. A. and J. A. Holbrook III. 1978. Sauger, walleye, and yellow perch in the southeastern United States. Pages 74-81. *In* R. L. Kendall, ed. Symposium on Selected Coolwater Fishes of North America. Special Publ. No. 11, Amer. Fish. Soc., Washington, D.C.

Hokanson, K.E.F. 1977. Temperature requirements of some percids and adaptations to the seasonal temperature cycle. J. Fish. Res. Board Can. 34(10): 1524-1550.

Jones, F. V., W. D. Pearson, and L. C. Fitzpatrick. 1977. Production of a fish taxocene in a Texas pond. Env. Biol. Fish. 2(3): 241-259.

Lemke, A. E. 1977. Optimum temperature for growth of juvenile bluegills. Prog. Fish-Cult. 39(2): 55-57.

Mahon, R. 1977. A second look at bluegill production in Wyland Lake, Indiana. Environmental Biol. of Fishes. 1(1): 85-86.

McCormick, J. H. 1976. Temperature effects on young yellow perch, *Perca flavescens* (Mitchell). U.S. Environ. Prot. Agency, Duluth, MN. EPA-600/3-76-057. 18 pp.

McCormick, J. H. and C. F. Kleiner. 1976. Growth and survival of young-of-the-year emerald shiners (*Notropis atherinoides*) at different temperatures. J. Fish. Res. Board Can. 33(4): 839-842.

Prentice, J. A. 1977. Statewide walleye stocking evaluation. Federal Aid Project F-31-R-3, Texas Parks and Wildl. Dept. 45 pp.

Prentice, J. A. and W. J. Dean, Jr. 1977. Effect of temperature on walleye egg hatch rate. Proc. Southeast. Game and Fish Comm., Vol. 31 (in press).

Prentice, J. A. and R. D. Clark, Jr. 1978. Walleye fishery management program in Texas - a systems approach. Pages 408-416. *In* R. L. Kendall, ed. Symposium on Selected Coolwater Fishes of North America. Special Publ. No. 11, Amer. Fish. Soc., Washington, D.C.

Regier, H. A. 1963. Ecology and management of largemouth bass and bluegills in farm ponds in New York. N.Y. Fish and Game J. 19(1): 1-89.

Ricker, W. E. 1945. Natural mortality among Indiana bluegill sunfish. Ecology, 26(2): 111-121.

Ricker, W. E. 1946. Production and utilization of fish populations. Ecol. Monogr. 16: 373-391.

Smith, L. L., Jr. and W. M. Koenst. 1975. Temperature effects on eggs and fry of percoid fishes. U.S. Environ. Prot. Agency, Duluth, MN. EPA-660/3-75-017. 91 pp.

Stauffer, J. R., Jr., K. L. Dickson, J. Cairns, Jr., and D. S. Cherry. 1976. The potential and realized influences of temperature on the distribution of fishes in the New River, Glen Lyn, Virginia. Wildlife Monogr., No. 50. 40 pp.

Stroud, R. H. 1949. Growth of Norris Reservoir walleye during the first 12 years of impoundment. J. Wildl. Mange. 13(2): 157-177.

Swingle, H. S. 1950. Relationships and dynamics of balanced and unbalanced fish populations. Bull. 274, Agric. Exp. Station, Auburn, Alabama.

Toetz, D. W. 1967. The importance of gamete losses in measurements of freshwater fish production. Ecology 48: 1017-1020.

Walker, R. E. and R. L. Applegate. 1976. Growth, food, and possible ecological effects of young-of-the-year walleyes in a South Dakota prairie pothole. Prog. Fish-Cult. 38(4): 217-220.

SECTION 5

BLUEGILL REPRODUCTION

INTRODUCTION

Reproduction of bluegill (*Lepomis macrochirus*) has been studied extensively throughout the geographical range of this species, but maximum temperatures associated with these natural spawning populations were usually less than 30° C (Carlander, 1977). However, Clugston (1966) observed natural spawning of bluegill at 32° C in southern Florida. In the laboratory, artificially spawned bluegill eggs were incubated and hatched at 34° C but with 50% mortality (Banner and Van Arman, 1973). Results from other studies indicate that the hatching success of artificially fertilized bluegill eggs is less than that for naturally spawned eggs regardless of temperature (Nakamura *et al*., 1971; Toetz, 1966).

In conjunction with the evaluation of temperature effects on other aquatic communities in 12 outdoor, experimental channels, the objectives of this phase of the experiment were: (1) to evaluate the effects of elevated temperatures on bluegill reproduction under natural spawning conditions and (2) to evaluate the effects of temperature on the resulting standing stocks of young-of-the-year (YOY) bluegill which served as the food source for the top predator in the channels, juvenile walleye (*Stizostedion vitreum vitreum*). Results from previous studies under ambient temperature conditions showed that bluegill were prolific spawners in the channels and that YOY standing stocks of 200 to 300 kg/ha could be expected (Forsythe and Wrenn, 1978).

MATERIALS AND METHODS

The following parameters were used to evaluate bluegill reproduction: (1) onset and cessation of spawning, (2) hatching success, (3) mean number of larvae per nest, (4) relative abundance of postlarvae, and (5) biomass and numbers of YOY bluegill recovered by rotenone. Evaluation of parameters 1, 2, and 3 were limited to the upper channel sections within each temperature regimen, where nesting substrates were added.

Although bluegill had previously spawned successfully in the channels which contained two substrates, clay-silt in pool areas and limestone rock (5-30 cm diameter) in the shallow zones, we anticipated that the addition of gravel in specific areas would concentrate spawning in those areas and thus facilitate observations. Smith (1975) reported spawning in two *Lepomis* species in aquaria containing pans filled with gravel. In this study, nine galvanized pans (9.5 cm deep x 42 cm diameter), coated with epoxy paint and filled with gravel (0.5-2.5 cm diameter), were placed on the rock areas in the upper section of each channel. In the divided channels, approximately 30 females and 30 males had access to the nest pans, whereas, in the undivided channel, ca. 75 females and 75 males had access. Pans were placed adjacent to outer channel walls at a depth of 0.3 m, and the tops of pans were flush with the bottom contour. To determine the onset and cessation of spawning these pans were inspected daily with the aid of an underwater viewer constructed of a piece of clear plastic glued to a 0.6 m section of 7.5 cm diameter PVC pipe.

Hatching success of eggs was determined for a minimum of 10 nests from each temperature regimen. After the male bluegill had constructed the nest, three beaker coverglasses (6.4 cm diameter) were placed near the center of the nest. After spawning had occurred, the coverglasses and adhering eggs were transferred to a 1-liter wide-mouth plastic jar. The mouth of the jar was covered with fine-meshed netting and replaced adjacent to the nest. After 48 hours the jar was removed from the channel, and the newly hatched larvae and dead eggs were counted to determine percent hatch.

We found in preliminary trials that it was practically impossible to count or estimate the eggs per nest; however, it was possible to remove the nest pan and count the larvae that hatched. The entire pan of gravel was washed through a series of sieves. The larvae were recovered and placed in a beaker to which water was added to make a volume of 300 ml. The larvae were counted in five 10-ml subsamples, and the mean was used to compute the total number of larvae per nest.

Relative abundance of postlarval bluegill was determined from biweekly tows with a No. 10 plankton net (153 μ mesh), mouth diameter 30 cm. The frame of the net was mounted on a pole and horizontal tows were taken just below the surface in pool areas of the channels. The distance towed was 25.6 m in the upper channel sections and 39.3 m in the lower sections. Assuming 80% filtering efficiency (Cummins *et al.*, 1969), the volume filtered was 1.45 and 2.22 m^3, respectively. All samples were collected between 2200 and 2400 hr CDT.

Biomass and total number of YOY bluegill in each population were determined when all fish were removed with 3 mg/liter rotenone (9 September).

RESULTS

Bluegill readily spawned in the gravel-filled pans and seemed to prefer this substrate rather than the clay-silt or larger limestone rocks. In the upper sections of the divided channels, the pans appeared to be used exclusively for nesting sites. In the undivided channels, which also had pans only on the first two rock areas, the pans were used extensively but spawning was also observed on rock areas without pans. Spawning usually occurred between 0900 and 1500 hours. Initially, males constructed nests as long as one week before eggs were deposited, but later in the season nest construction preceded spawning by only one or two days. Numerous nests were constructed in which spawning did not occur; however, individual nest sites were used repeatedly at irregular intervals throughout the summer in all four temperature regimens. On nine occasions, two separate nests were observed within a single pan.

Spawning occurred first in the +6 C regimen on 28 April at 23° C. Spawning began in the +4 C, +2 C, and ambient regimens on 5 May, 9 May, and 24 May at respective temperatures of 24°, 23°, and 24° C. Spawning continued throughout the summer and ended during the last week of August in all temperature regimens (Fig. 3). Cessation of spawning was confirmed by examining the gonads of bluegill recovered at the end of the experiment on 9 September. Maximum temperatures at which spawning was observed in the four temperature regimens of ambient, +2, +4, and +6 C were 30.8°, 32.1°, 33.4°, and 34.2° C, respectively.

A grand total of 1,049 nests with eggs were observed. The total in the upper sections of the two divided channels in each temperature treatment was: ambient - 137, +2 C - 142, +4 C - 194, and +6 C - 200. Adding the number of nests from the undivided channels, there was a total of 217, 199, 319, and 314 observed spawns in the respective treatments. Assuming there were 30 females in each upper section of a divided channel, the mean number of spawns per female in the respective temperature regimens was: 2.3, 2.4, 3.2, and 3.3. We saw no relationship between temperature and the period of time between spawns per female. Male to female sex ratios of the adult bluegill recovered from the upper sections at the end of the experiment were as follows: 1:1.2 (ambient), 1.3:1 (+2 C), 1:1 (+4 C), and 1.1:1 (+6 C).

Hatching Success

Bluegill eggs hatched at temperatures ranging from 23° to 34° C. Mean hatching success was 95% (range 76-99) and there appeared to be no relationship between hatching success and temperature (Fig. 4). The incubation period ranged from 24 to 40 hours; however, any relationship with temperature was not quantified since it was often difficult to determine the exact time of spawning. Mean number of prolarvae per nest, on the basis of 18 nests sacrificied, was 5,939 (range 1,118-14,484). The estimated mean total number of larvae produced (number of nests X mean number of larvae) in upper sections of the divided channels ranged from 406,000 in the ambient regimen to 593,000 in the +6 C regimen (Table 12).

The size of 50 fertilized eggs (1-3 hrs old) was as follows: total diameter 1.7 ± 0.23 mm, yolk diameter 1.01 ± 0.06 mm, and oil droplet diameter 0.29 ± 0.03 mm. Total length of 50 newly hatched larvae was 3.45 ± 0.11 mm. Based on measurements of 14 specimens, larvae at swim-up had a total length of 4.89 ± 0.25 mm. Larvae remained in the nest from 2 to 4 days before swim-up. As water temperature increased, larvae absorbed yolk materials sooner and spent less time in the nest; however, no attempt was made to quantify this relationship.

Relative Abundance and Biomass

Peak densities of postlarval bluegill as determined from net tows ranged from 50/m^3 in the +2 C channels to 150/m^3 in the ambient channels.

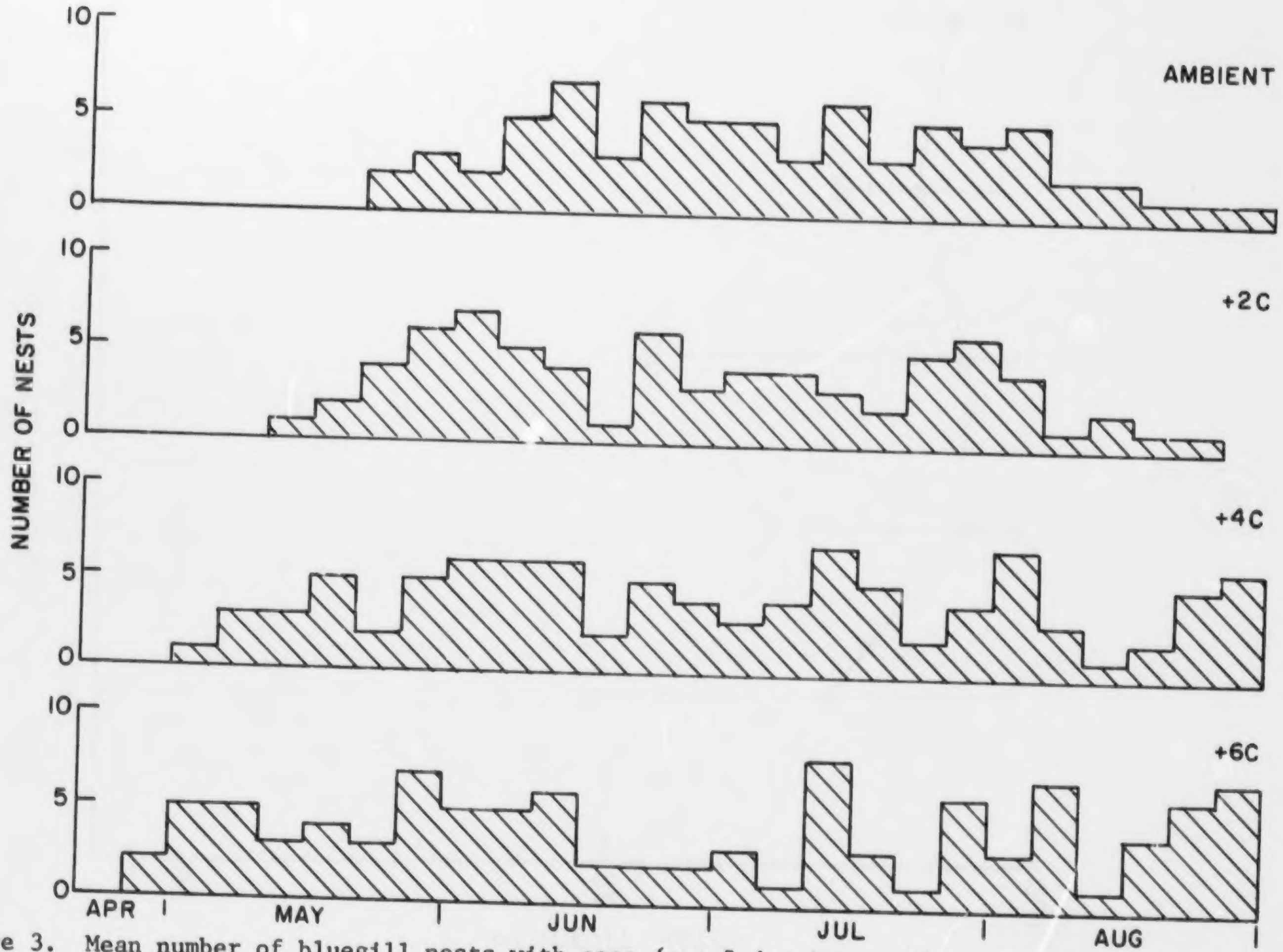

Figure 3. Mean number of bluegill nests with eggs (per 5-day interval) in the upper sections of divided experimental channels for four temperature regimens, ambient (Tennessee River), and +2°, +4°, and +6° C above ambient.

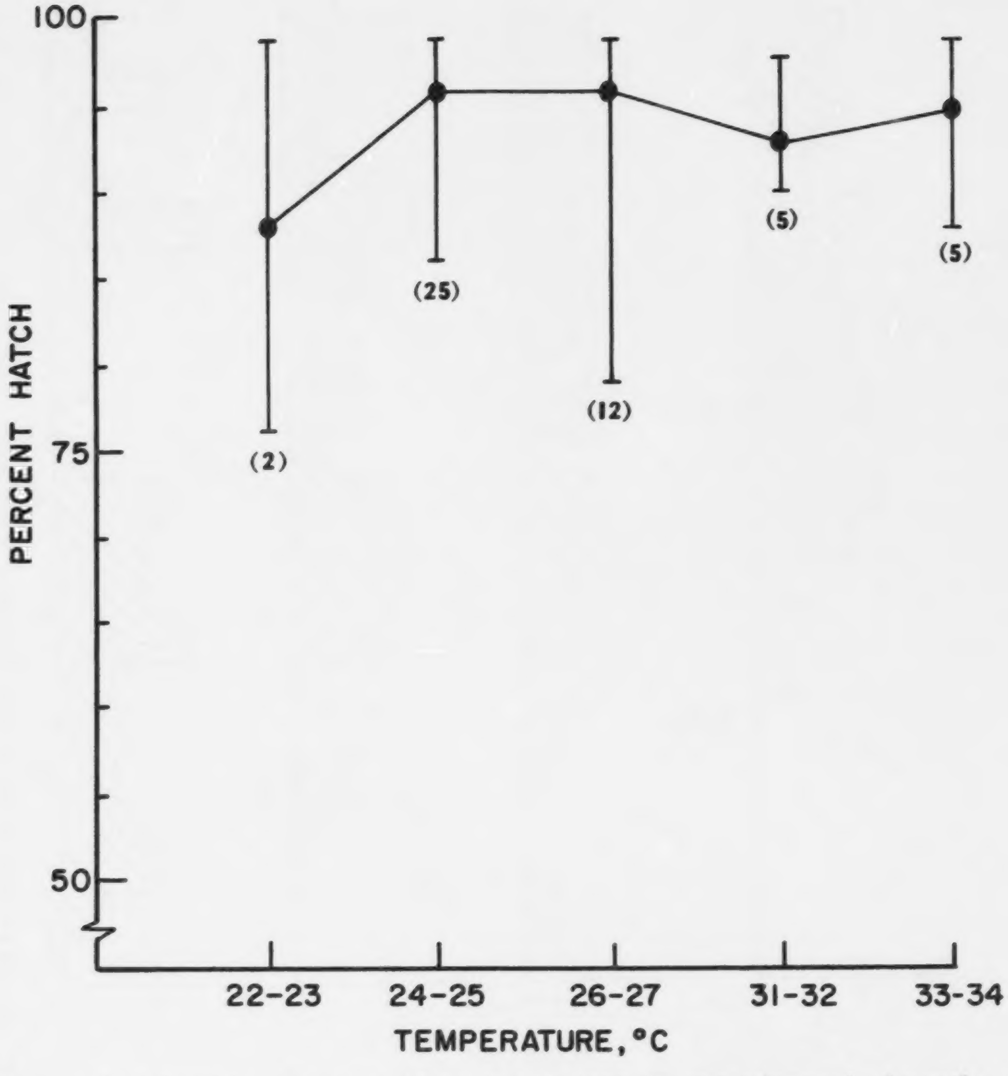

Figure 4. Hatching success of bluegill eggs in experimental channels, vertical lines denote range. Number of nests observed in ( ).

TABLE 12. TOTAL LARVAE PRODUCED AND STANDING STOCKS OF YOUNG-OF-THE-YEAR BLUEGILL RECOVERED FROM UPPER CHANNEL SECTIONS.

Temperature Regimen[a]	Total No. Nests[b]	No. Larvae Produced (X 1000)	Standing Stock	
			No.	Biomass, kg/ha
Ambient	75	445	8,499	246
	62	368	10,368	294
+2 C	74	439	10,812	179
	68	403	12,552	268
+4 C	80	475	14,182	272
	114	677	11,910	160
+6 C	87	516	8,293	272
	113	671	8,354	265

[a] Ambient temperature of Wheeler Reservoir, Tennessee River, or elevated +2, +4, and +6° C.

[b] Mean number of larvae per nest - 5,939.

The mean peak density was ca. $100/m^3$ for all temperature regimens. Since there was approximately 200 m^3 of water in an upper section, estimated peak abundance was 20,000 in these sections. Mean total length of larvae captured in tow nets was 5.69 ± 0.98 mm (range 5-11 mm).

Although spawning continued throughout most of August in all temperature regimens, drastic declines in the number of postlarval bluegill captured in net tows occurred in each treatment. These declines, which occurred in the same sequence as the onset of spawning, i.e. +6, +4, +2, and ambient, were attributed to intense predation on eggs and swim-up larvae by the larger juvenile bluegill. Nest predation became intense in the four temperature regimens on the following dates: +6 C - 29 June, +4 C - 5 July, +2 C - 15 July, and ambient - 27 July. Juveniles were observed feeding in nests, and stomachs of juveniles (15-30 mm TL) captured adjacent to nests contained as many as several hundred eggs and larvae.

Mean biomass of YOY bluegill recovered from the upper channel sections ranged from 4.1 kg (216 kg/ha) in the +4 C regimen to 5.2 kg (270 kg/ha) in the ambient regimen (Table 12). Mean number recovered ranged from 13,046 (686,000/ha) in the +4 C regimen to 8,323 (438,000/ha) in the +6 C treatment. In the lower sections of the two divided channels in each treatment, mean biomass ranged from 3.6 kg (123 kg/ha) in the +4 C channels to 6.4 kg (220 kg/ha) in the ambient channels. In the undivided channels, biomass ranged from 5.9 kg (124 kg/ha) in the +4 C regimen to 10.3 kg (214 kg/ha) in the +6 C regimen. Statistical analyses of the biomass between treatments are presented in Section 4.

DISCUSSION

Although considerable variation is seen in the reproductive timing mechanisms of teleosts, photoperiod and temperature have been the most frequently studied environmental factors (De Vlaming, 1972). This author also noted that a confounding factor in evaluating photoperiod and temperature is that photoperiodism seems to be temperature-sensitive in the majority of species studied. Stevenson *et al.* (1969) reported that temperature was the key environmental factor controlling bluegill reproduction in an Ohio pond. For the pumpkinseed, *Lepomis gibbosus*, Burns (1976) indicated that spring recrudescense was controlled by temperature but that fall cessation was not. Our results also indicated that initiation of spawning for bluegill was controlled by temperature and that the cessation of spawning, which occurred the last week of August (Fig. 3), was not. However, Clugston (1973) collected ripe bluegill from a reactor cooling reservoir throughout the year and concluded that spawning can occur during almost any month of the year if the water temperature has been above 20° C. Since our study was concluded on 9 September, we can only speculate that spawning could have resumed later in September or October; however, from November through March we cannot maintain temperatures above 20° C at this facility.

In the present study, mean daily temperatures that reached 34° C did not inhibit spawning, and the minimum temperature at which spawning occurred was 23° C (further results obtained in 1978 indicate that spawning was not inhibited at 37° C). Periods of decreasing water temperatures inhibited nesting activity and at times caused males to desert nests in all temperature regimens. In June, a temperature drop of 3° to 4° C (from 30° to 26° C) in the +6 C channels, disrupted nesting activity and several nests suffered mortalities of eggs or larvae. Hunter (1963) also observed a decline in spawning activity of *Lepomis cyanellus* when water temperatures were decreasing.

On the basis of 50% mortality, the upper and lower temperatures for hatch of normal bluegill fry in the laboratory was 33.8° and 21.9° C, respectively (Banner and Van Arman, 1973). Our results showed a 95% hatching success of normal fry at ca. 34° C. Factors that may have attributed to this higher hatching success were: (1) acclimation temperature of adults, (2) method of fertilization, and (3) conditions during incubation. The adult bluegill in the channels were acclimated to the same temperature (34° C) at which spawning occurred; whereas, in the laboratory study, the adults were acclimated at 26° C prior to spawning. As opposed to natural fertilization of eggs in the channels, eggs in the laboratory were stripped from females receiving harmone injections and artificially fertilized. Various experiments with the artificial fertilization of bluegill eggs have yielded a hatching success of 50% under normal temperature conditions (Nakamura *et al.*, 1971; Smitherman and Hester, 1962; Toetz, 1966). A third factor which may have enhanced hatching success of natural spawns in the channels was that numerous invertebrates, including amphipods (*Hyalella azteca* and *Crangonyx* sp.), were present in the nest pans. Oseid (1977) reported that amphipods (*Asellus militaris* and *Gammarus pseudolimnaeus*) eliminated fungus-related mortalities on embryos of white sucker (*Catostomus commersoni*) and walleye.

Multiple spawning by female bluegill, which we observed in the present study, has been observed under laboratory conditions. Nakamura *et al.* (1969) reported that female bluegill spawned 4 or 5 times during one breeding season. The highest mean number of spawns per female in our study was 3.3 which occurred in the +6 C regimen. However, in one of the replicates at this treatment females apparently spawned 4 to 5 times. From 60 bluegills stocked initially, 19 females and 31 males were recovered at the end of the study. Five females died during the course of the study. The number of nests with eggs observed in this channel was 113.

Although the total number of spawns was highest in the upper sections of the +4 and +6 C channels, the biomass of YOY recovered was not significantly different between treatments (Table 12). Since hatching success was not inhibited by temperature in any of the elevated temperature regimens, other factors were apparently involved in equalizing the standing stocks. Walleye predation pressure may have been greater in the higher treatments; however, in the +6 C regimen (upper sections) all the walleye had apparently succumbed to the high temperatures by mid-August. We concluded that the greatest impact on reducing the YOY biomass in channels with the higher total spawns, was the intense predation by juveniles on the eggs and larvae. Apparently the number of larvae surviving through the swim-up stage was inversely proportional to the number of larger juveniles in each population. Therefore, any advantage that was gained by the earlier spawning, and thus a greater number of spawns, in the warmer temperature regimens was negated by this intense predation. This density-dependent or "compensatory" mortality is common for many species of fish (Ricker, 1954; Nikolskii, 1962).

Standing stocks of YOY bluegill in the upper sections of the channels divided by screen barriers (2-mm mesh) was significantly higher than those in the lower sections (see Section 4). This was considered to be a barrier-effect rather than temperature. These differences were probably influenced by two factors, spawning substrate and food supply. Gravel-filled nest pans, which appeared to be used exclusively when available, were placed only in the upper sections. Apparently this provided an optimum substrate for spawning that enhanced larval survival. The second factor was food supply. Zooplankton densities were also higher in the upper sections of the divided channels (see Section 6). Larval fish densities have been correlated with food supply in various studies (Crawford, 1923; Emig, 1966; Hall *et al.*, 1970).

In summary, we conclude that: (1) initiation of spawning was controlled by temperature and spawning occurred earlier in the elevated temperature regimens, (2) temperature had no direct effect on numbers and biomass of YOY bluegill recovered, (3) there was no relationship between number of spawns and biomass of YOY bluegill recovered, and (4) YOY bluegill provided an abundant food source for the walleye.

REFERENCES

Armitage, B. J., T. D. Forsythe, E. B. Rodgers, and W. B. Wrenn. 1978. Browns Ferry Biothermal Research Series I. Colonization by periphyton, zooplankton, and macroinvertebrates. U.S. Environ. Prot. Agency, Duluth, Minn. EPA-600/3-78-020, 46 pp.

Banner, A. and J. A. Van Arman. 1973. Thermal effects on eggs, larvae, and juveniles of bluegill sunfish. U.S. Environ. Prot. Agency, Duluth, Minn. EPA-R3-73-041, 111 pp.

Burns, J. R. 1976. The reproductive cycle and its environmental control in the pumpkinseed, *Lepomis gibbosus* (Pisces: Centrarchidae). Copeia 1976(3): 449-455.

Clugston, J. P. 1966. Centrarchid spawning in the Florida Everglades. Quart. J. Florida Acad. Sci., 29: 137-143.

----------. 1973. The effects of heated effluents from a nuclear reactor on species diversity, abundance, reproduction, and movement of fish. Ph.D. Dissertation, Univ. Georgia. 104 pp.

Cummins, K. W., R. R. Costa, R. E. Rowe, G. A. Moshiri, R. M. Scanlon, and R. K. Zajdel. 1969. Ecological energetics of a natural population of the predaceous zooplankton *Leptodora kindtii* (Focke) (Crustacea: Cladocera). Oikos 20: 189-223.

Crawford, D. R. 1923. The significance of food supply in larval development of fishes. Ecology 4(2): 147-153.

De Vlaming, V. L. 1972. Environmental control of teleost reproductive cycles: A brief review. J. Fish. Biol. 4: 131-140.

Emig, John W. 1966. Bluegill sunfish. *In* Inland Fisheries Management (Alex Calhoun, ed.). California Dept. Fish and Game, pp. 375-391.

Forsythe, T. D. and W. B. Wrenn. 1978. Predator-prey relationships among walleye and bluegill in experimental ecosystems. *In* H. Clepper (ed.), An International Symposium on Predator-Prey Systems in Fish Communities and Their Role in Fisheries Management, Atlanta, GA, July 1978 (in press).

Hall, D. J., W. E. Cooper, and E. E. Werner. 1970. An experimental approach to the production dynamics and structure of freshwater animal communities. Limnol. Oceangr., 15(6): 839-929.

Hunter, J. R. 1963. The reproductive behavior of the green sunfish, *Lepomis cyanellus*. Zoologica 48(1): 13-24.

Nakamura, N., S. Kashara, and T. Yada. 1969. Studies on the usefulness of the bluegill sunfish, *Lepomis macrochirus*, as an experimental standard animal, I. On the breeding habits. J. Fac. Fish. and Animal Husbandry, Hiroshima Univ., 8(1): 1-11.

----------, S. Kashara, and T. Yada. 1971. Studies on the usefulness of the bluegill sunfish, *Lepomis macrohirus*, as an experimental standard animal, II. On the development stages and growth from the egg through one year. J. Fac. Fish. and Animal Husbandry, Hiroshima Univ., 10(2): 140-151.

Nikolskii, G. V. 1962. On some adaptations to the regulation of population density in fish species with different types of stock structure. pp. 265-280, *In* The Exploitation of Natural Animal Populations (Le Cren, E. D. and M. W. Holdgate, eds.), B.E.S. Symp. No. 2, Oxford: Blackwell.

Oseid, M. 1977. Control of fungus growth on fish eggs by *Asellus militaris* and *Gammarus pseudolimnaeus*. Trans. Amer. Fish. Soc., 106(2): 192-195.

Ricker, W. E. 1954. Stock and recruitment. J. Fish. Res. Bd. Can., 11(5): 559-623.

Smith, W. E. 1975. Breeding and culture of two sunfish, *Lepomis cyanellus* and *L. megalotis*, in the laboratory. Prog. Fish-Cult., 37(4): 227-229.

Smitherman, R. O. and F. Eugene Hester. 1962. Artificial propagation of sunfishes, with meristic comparisons of three species of *Lepomis* and five of their hybrids. Trans. Amer. Fish. Soc., 91(4): 333-341.

Stevenson, F., W. T. Momot, and F. J. Svoboda, III. 1969. Nesting success of the bluegill, *Lepomis macrochirus* (Rafinesques), in a small Ohio farm pond. Ohio J. Sci., 69(6): 347-355.

Toetz, D. W. 1966. The change from endogenous to exogenous sources of energy in bluegill sunfish larvae. Invest. Indiana Lakes and Streams, 7(4): 115-146.

SECTION 6

ZOOPLANKTON

INTRODUCTION

The impact of heated water discharges from electrical generating plants on zooplankton communities in reservoirs is difficult to assess in the field. Utilizing large-scale microcosms, a series of temperature-controlled experiments are planned in an attempt to elucidate the ecological consequences of elevated temperature regimens on zooplankton communities. These are the findings of the first elevated temperature study, whereby temperature was incremented above ambient at 2°, 4°, and 6° C for a 185-day period beginning in March 1977. Crustacean zooplankton were studied from March through August 1977.

Prior to this study a two year study was conducted to determine the impact of bluegill predation on zooplankton community structure (Forsythe, 1978). Cladocerans such as *Daphnia*, *Simocephalus*, *Ceriodaphnia*, and *Bosmina* were always abundant in the absence of bluegill predation or when predation pressure was not intense. With increasing intensity of bluegill predation pressure, *Daphnia* quickly disappeared, *Ceriodaphnia* became very rare, *Simocephalus* was significantly reduced in numbers, and *Bosmina* maintained a sizable population density. With further increases in bluegill predation, the ostracod *Physocypria* and the copepod *Mesocyclops* became the dominant taxa. Bluegill predation can become so intense that zooplankton community biomass is held low, species diversity is low, and bluegill begin feeding on vegetation. Only in the presence of a piscivore which could control young bluegill numbers was zooplankton community biomass and species diversity able to reach proportions similar to natural reservoir conditions.

The purpose of this study was to determine gross effects of elevated temperature regimens on crustacean zooplankton community structure. Subsequent studies will take a more mechanistic approach to determine cause/effect relationships.

Although many controlled experiments have been conducted to study the effects of elevated temperature on single zooplankton populations, only one study assessed changes in zooplankton community structure under controlled temperature conditions. Carlson (1974) treated replicate outdoor microcosms (small plastic swimming pools) to temperature increments of 5°, 7°, 14°, and 21° C above ambient and observed changes in the community composition of pond plankton inoculations over a 35-day period. His ambient temperature averaged 21° C and the four treatments averaged 25°, 27°, 31°, and 42° C.

In general, he noted a marked reduction in community density for the 14° C treatment above ambient and total mortality in the 21° C treatment above ambient. The 5° C treatment above ambient had the greatest zooplankton diversity and density; however, these were only slightly higher than the ambient's diversity and density. It is unlikely that the results of Carlson's study could be used to predict the ecological consequences of similar elevated temperatures in the field because (1) the duration of the study was relatively short (35 days); (2) the microcosms were small, lending to "enclosure effects"; and (3) most important, the microcosms lacked predation pressure by fish that zooplankton communities in nature encounter.

The results of the present study are the most comprehensive produced to date under controlled experimental conditions because: the channels are large compared to other microcosms; fish predation pressure was a force interacting with temperature stress; and the studies ran for 185 days.

MATERIALS AND METHODS

Descriptions of the experimental channels, the heated water treatments, and the stocking of bluegill and walleye are given in other sections of this report.

Prior to this study, zooplankton were studied in the channels for three years under ambient temperature conditions (Armitage *et al.*, 1978 and Forsythe, 1978). The primary problem associated with studying zooplankton communities in shallow-water environments is that of obtaining representative samples. The channels each contained five pools and five shallow rock areas; therefore, there were two habitat-types and ten microhabitats. Among these microhabitats the zooplankton exhibited considerable spatial and temporal variability in their distribution patterns within a channel. During daylight hours as much as ninety percent of the zooplankton community biomass was found concentrated within 20 cm of channel walls, pool bottoms, and rock areas. These areas contained dense growths of filamentous algae and, in the case of pool bottoms, *Chara* was often present. After sunset most of the zooplankton populations migrated from the daytime habitats to become fairly evenly distributed throughout the pools and remain dispersed as such until sunrise.

Several types of sampling gear were tested. The most practical and efficient means of sampling was to tow a plankton net horizontally over the entire length of a channel. This method was further modified by mounting a 30-cm diameter (mouth opening) plankton net on a wooden pole (Forsythe, 1978). An 80-µ mesh net sampled most zooplankton taxa but usually became excessively clogged before the length of one channel could be sampled. A 153-µ mesh net sampled most of the microcrustacean species but was ineffective at sampling planktonic rotifers and copepod nauplii. The 153-µ mesh net was selected for this study because the zooplankton community biomass was dominated by microcrustaceans and these plankters were the major food items consumed by young bluegill produced in the channels.

Several twenty-four hour sampling studies were conducted prior to this study with the objective of developing a sampling scheme which would give representative and quantitative estimates of microcrustacean community composition and population densities with a minimal amount of sampling and enumeration effort. These twenty-four hour studies were conducted quarterly for one year. Each study consisted of taking four replicate samples in a channel at two-hour intervals for twenty-four hours. Two subsample counts were made on each sample. The variance components from an analysis of variance for total microcrustacean densities showed 84% of the experimental variance was due to the hour-of-day the samples were taken, 7% was due to sampling replication error, and 8% was due to subsampling and counting error (Forsythe, 1978). Therefore, the most representative and quantitative samples could be collected at night, a time when most zooplankton species migrated into open water from daytime habitats where they were concentrated near channel structure and algal vegetation.

For the present study, zooplankton were collected biweekly and at three hours after sunset. Replicate sampling and subsample counting were considered unnecessary because the major source of error was the time of sampling. Initially, the entire length of each channel was sampled, even though eight of the twelve channels were partitioned with 2-mm mesh screens (see Sections 3 and 4 of this report). It was assumed the screens would not partition zooplankton populations within a channel, however, by June the density and species composition of microcrustaceans were noted to differ in the upper and lower sections of the four partitioned channels. The sampling was modified so that the upper and lower sections of each channel were sampled, giving two samples per channel rather than just one. Undivided channels were sampled in the same manner as the divided channels.

The plankton net filtering efficiency was determined to be 80% and the volumes filtered for upper, lower, and whole channel samples were calculated to be 1.4, 2.2, and 3.6 m^3, respectively.

Identification and enumeration of zooplankton was made using an inverted microscope and a plankton counting chamber designed to hold a 5-ml subsample. The samples were preserved in formalin and brought to a volume of 100 ml before subsampling.

Cladocerans and cyclopoids were identified to species except for some chydorids which were taken only to genus. Calanoids were rare, except for one species, and were not identified. Ostracods were identified to genus. Micrometer measurements of dominant taxa were made periodically to obtain mean body-sizes.

Population densities were calculated by assuming an even distribution of zooplankton at the time of sampling and no plankton net avoidance by the zooplankters. Densities (reported as number/m^3) were converted to biomass using literature dry-weight values in relation to mean body-size as determined in other studies (Hall *et al.*, 1970; Dumont *et al.*, 1975). Community and population biomass was reported as mg/m^3 (dry-weight). Shannon-Weaver diversity was calculated for each sample on each sampling date.

RESULTS

Before the channels were constructed, it was postulated that the channels would not colonize with an abundance of zooplankton because of the flow-through design. It was assumed that the species present would primarily be limnoplanktonic forms pumped from the reservoir. However, the channels colonized with a diverse assemblage of limnozooplankton, heleozooplankton, and benthic forms soon after they were put in operation in 1974 (see Armitage *et al.*, 1978).

A list of the crustacean zooplankton taxa observed from the March through August 1977 study shows that the taxa generally considered to be heleozooplankton and benthic forms far outnumbered the limnozooplankton forms (Table 13). The dominant species coming into the channels (intake sampling) from the reservoir were *Diaphanosoma* sp., *Daphnia retrocurva*, *Diaptomus* sp., *Bosmina longirostris*, and *Mesocyclops edax*. Only the latter two species were abundant in channel samples. The density of crustacean zooplankton in the channels was always greater than incoming densities by orders of magnitude.

The five most abundant zooplankton populations collected during the study period were the same five taxa in all twelve channels (Fig. 5). The combined densities of the copepod-*Mesocyclops edax*, the ostracod-*Physocypria* sp., and the cladocerans-*Bosmina longirostris*, *Chydorus sphaericus*, and *Simocephalus vetulus* made up about 75% of the total crustacean zooplankton densities in each channel when densites on each sampling date (14 dates) were averaged to give mean abundances over the study period. The combined densities of *Mesocyclops* and *Physocypria* made up 50% of the total zooplankton density in each temperature treatment.

Fluctuation in population density of the five most abundant taxa exhibited slight differences in the timing and the magnitude of population peaks (Fig. 6). Temporal synchrony in the dicyclic population maxima of *Bosmina* was observed for all four temperature treatments, suggesting these plankters come primarily from the reservoir and are influenced little by elevated temperature once in the channels.

Simocephalus exhibited population maxima two months earlier in all three elevated temperature treatments compared to the ambient channels (16 March vs. 18 May).

Chydorus population maxima occurred two weeks earlier in all three elevated temperature treatments compared to ambient channels (19 May vs. 3 June) with the maximum densities similar in magnitude for all four treatments.

Physocypria exhibited dicyclic population maxima in all four treatments with the first maxima peak coinciding with that for *Chydorus*. The second density maxima occurred on 20 July in all four treatments.

Mesocyclops became abundant on 3 June in all four treatments and remained abundant for the duration of the study.

TABLE 13. ZOOPLANKTON TAXA OBSERVED IN CHANNELS OVER STUDY PERIOD AND MEAN DRY WEIGHT (μg) PER INDIVIDUAL.

Major Group	Group	Taxa	Dry Weight
Cladocera			
	Daphnidae		
		Ceriodaphnia quadrangula	2.0
		C. reticulata	2.0
		Daphnia ambigua	8.0
		D. catawba	10.0
		D. laevis	18.0
		D. parvula	10.0
		D. pulex	14.0
		D. retrocurva	12.0
		Moina affinis	5.0
		Scapholeberis kingi	3.0
		Simocephalus serrulatus	12.5
		S. vetulus	12.5
	Sididae		
		Diaphanosoma brachyurum	4.0
		D. leuchtenbergianum	4.0
		Latona setifera	9.0
		Latonopsis occidentalis	9.0
		Sida crystallina	9.0
	Bosminidae		
		Bosmina longirostris	1.4
	Macrothricidae		
		Macrothrix rosea	2.0
		Ilyocryptus spinifer	3.0
	Chydoridae		
		Alona affinis	1.3
		A. costa	1.8
		A. karua	1.8
		A. monocantha	1.8
		A. quadrangula	2.2
		A. rectangula	1.8
		Camptocercus rectirostris	4.0
		Chydorus globosus	4.0
		C. sphaericus	1.4
		Disparalona rostrata	1.8
		Euryalona occidentalis	5.0
		Eurycercus lamellatus	15.0
		Kurzia latissima	5.0
		Leydigia leydigi	6.0
		L. acanthocercoides	6.0
		Pleuroxus denticulatus	2.0
Copepoda			
	Cylopoida		
		Cyclops bicuspidatus thomasi	8.0
		C. vernalis	8.0
		Eucyclops agilus	8.0
		E. prionophorus	8.0
		E. speratua	8.0
		Macrocyclops albidus	15.0
		Mesocyclops edax	8.5
		Copepodites	3.0
	Calanoida		
		Osphranticum labronectum	15.0
		Diaptomus sp.	10.0
Ostracoda			
	Cypridae		
		Cypridopsis sp.	6.0
		Physocypria sp.	6.0
		Stenocypris sp.	10.0

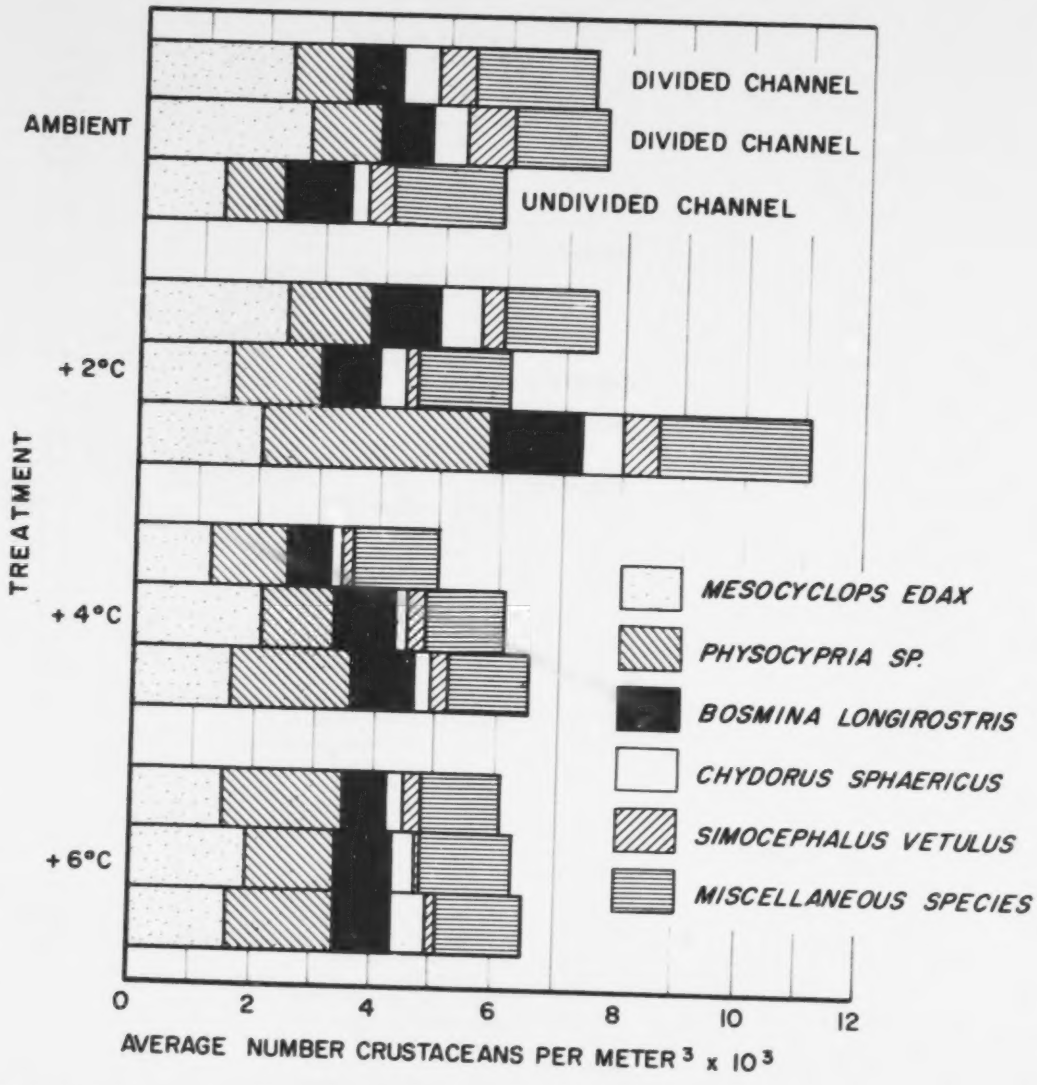

Figure 5. Mean zooplankton densities for each channel over the study period and the proportions of the five most abundant taxa.

Although the species diversity was generally highest in the ambient temperature channels and lowest in the highest temperature treatment (+6 C), the difference was not statistically significant when comparing the mean diversities over the study period ($\bar{X}$ ± SD; $T_o = 2.42 \pm 0.29$ vs. $T_6 = 2.24 \pm 0.30$; *t*-test, $P > .05$) (Fig. 3). The patterns of diversity fluctuations among treatments were remarkably similar over the study period. In each temperature treatment there was an increase in diversity during May with a maximum diversity in early June followed by a sharp decline.

The zooplankton counts were converted to biomass and combined into the three taxonomic groups of Cladocera, Copepoda, and Ostracoda. Cladocera consisted of about 15 taxa, Copepoda were represented mostly by six cyclopoids and one calanoid (*Osphranticum labronectum*). Ostracoda were mostly *Physocypria* with some *Cypridopsis* and very rarely *Stenocypris*. The temporal trend in these three groups show Cladocera was the dominant group during March, April, and May in each treatment but thereafter was the least abundant group (Fig. 7).

The temporal trends in total zooplankton standing crops show dicyclic maxima for the communities exposed to each temperature regimen (Fig. 7). The timing of the first maximum was two weeks sooner in all three elevated temperature regimens in relation to that in the ambient treatment (18 May vs. 3 June). The second maximum occurred on 20 July in all four treatments. The first peak was caused by increases in numbers of cladocerans. After May, the zooplankton community was overwhelmingly dominated by *Mesocyclops* and *Physocypria* in all four treatments.

The following results pertain to comparisons of upper and lower channel sections of divided and undivided channels. Figure 8 depicts the total zooplankton standing crops (averages for the June, July, and August period) and the average percentages contributed by the two dominant taxa, *Physocypria* sp. and *Mesocyclops edax*. Densities of the two taxa were compared directly (paired *t*-test) and percent abundances were compared after an arcsin transformation was made. Total zooplankton abundance (mean number m^{-3}) was significantly higher ($P < .001$) in the upper sections of the eight divided channels than in the lower sections across all treatments (Fig. 8). Abundance in the upper section of the four undivided channels were not significantly ($P > .05$) different from their respective lower sections.

There were considerable differences in the proportions of *Mesocyclops* and *Physocypria* among the respective upper and lower sections of the channels (Fig. 8). In all upper sections of the eight divided channels, *Mesocyclops* were significantly ($P < .001$) greater than *Physocypria*. In all lower sections of the eight divided channels, *Physocypria* was significantly ($P < .01$) more abundant than *Mesocyclops*. In the upper and lower sections of the four undivided channels, abundance of these two taxa were not significantly different. Although the mesh size (2-mm) of the screens that divided the channels was large enough to allow both *Mesocyclops* and *Physocypria* to pass through the dividers, apparently the dividers did act to isolate the two populations.

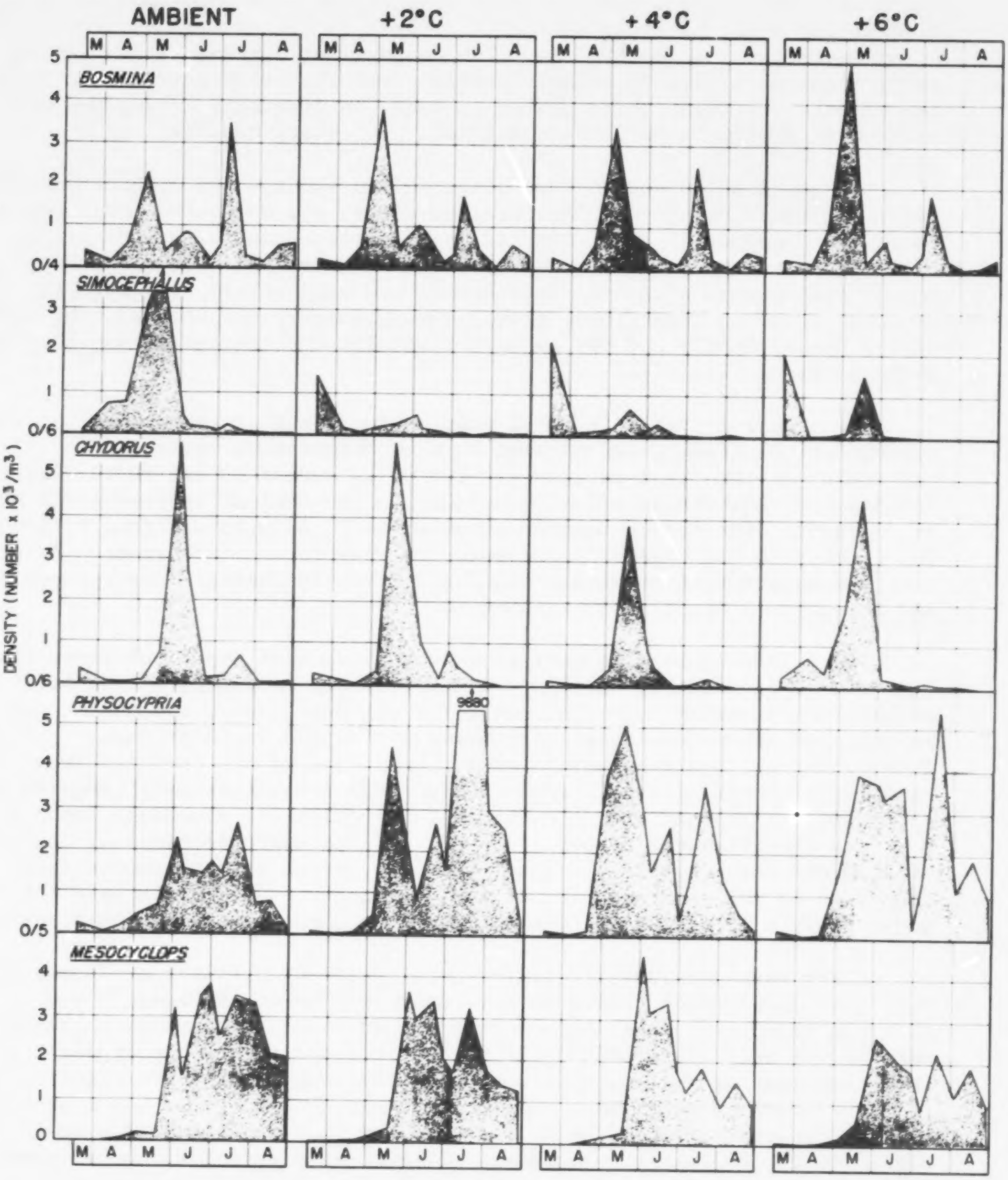

Figure 6. Time-series plots of mean densities per treatment for the five most abundant zooplankton taxa.

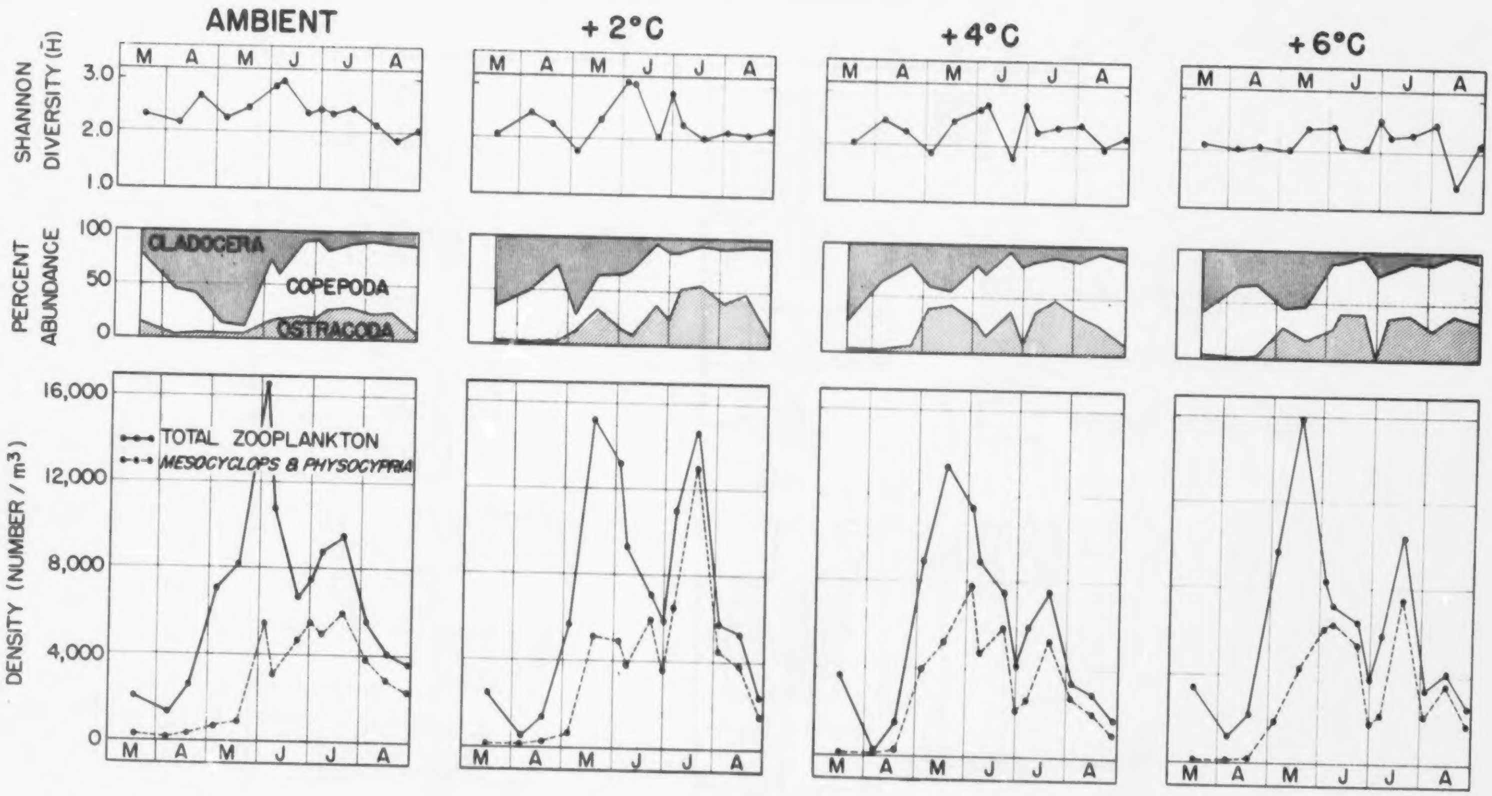

Figure 7. Time-series plots of Shannon diversity, community biomass composition, and total zooplankton density for each treatment.

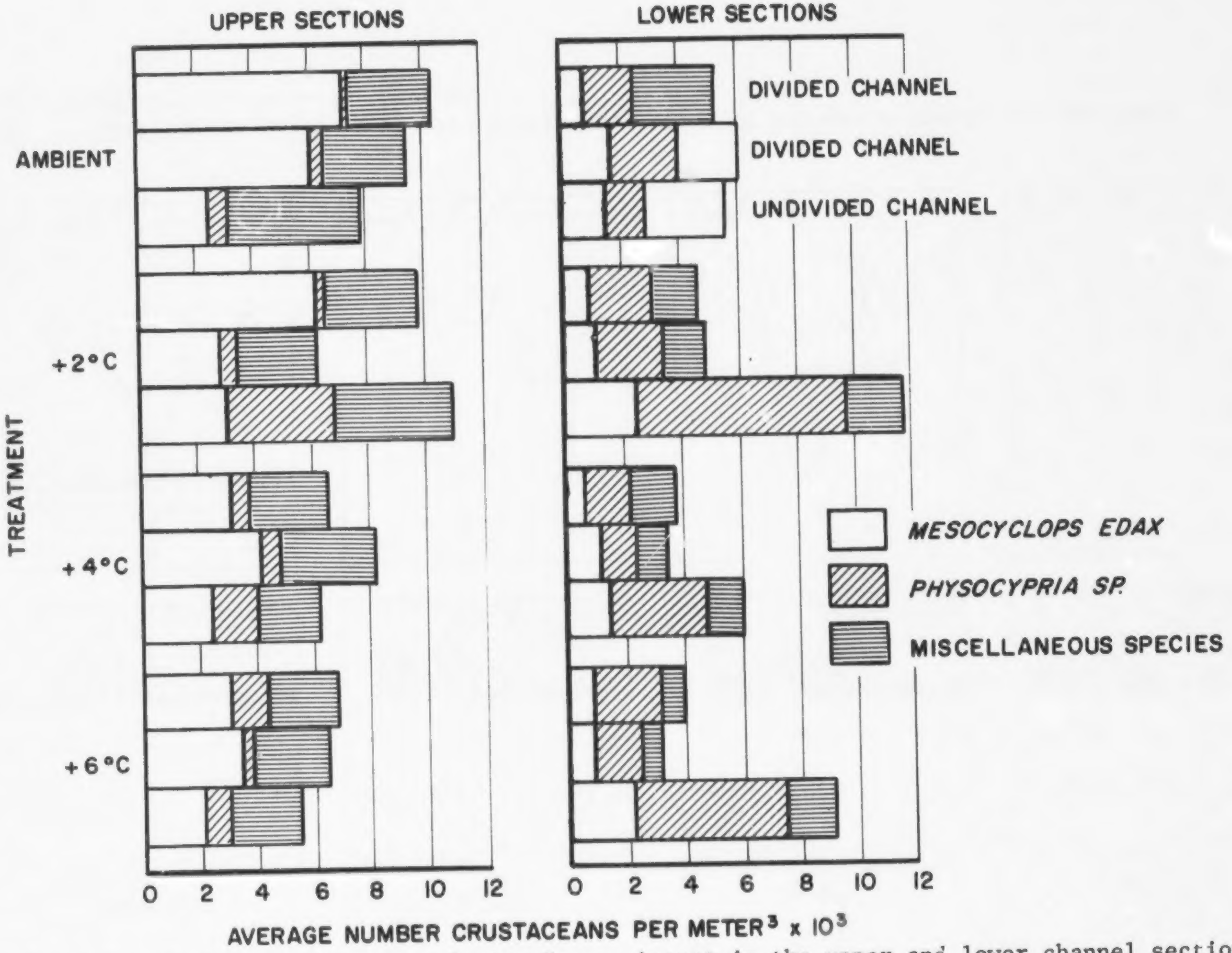

Figure 8. Mean zooplankton densities during June - August in the upper and lower channel sections of divided and undivided channels. Proportions represented by the two most abundant taxa are indicated.

Linear regression analysis was used to test for trends across treatment levels for zooplankton mean density and Shannon diversity averaged over the June-July-August period. For the upper and lower sections of the divided channels there was a statistically significant decreasing linear trend in zooplankton mean density with increasing temperature elevation (ANOVA with regression; $P < 0.05$); however, no such trend existed for the undivided channel (Fig. 9). Shannon diversity in the upper sections of the divided channels was greater in all heated channels than in ambient channels but a linear increasing trend was not found ($P < 0.25$). In the lower sections of the divided channels, zooplankton diversity was inversely related to temperature elevation ($P < 0.1$). Diversity trends were not evident in the upper or lower sections of the undivided channels.

DISCUSSION

There were few clearly defined temperature treatment effects on the zooplankton communities. Elevated temperature regimens produced no effect on total zooplankton densities or species composition of the five most abundant taxa (Fig. 10). Carlson (1974) also noted a lack of response by zooplankton communities to temperature elevations of 7° C above ambient. He did observe adverse effects from a 14° C temperature rise.

In this experiment, cladocerans were the most abundant zooplankters early in the study (March, April, May) but they decreased sharply as *Mesocyclops* and *Physocypria* increased. This pattern was similar in all four treatments and is attributed to increasing bluegill predation pressure due to continually increasing recruitment over time. In an earlier study at ambient temperatures (Forsythe, 1978), the same temporal changes in zooplankton community structure occurred in channels with bluegill, whereas in channels without fish, cladocerans dominated throughout the study period (May to October). When bluegill predation pressure is absent or of small magnitude, cladocerans apparently can out-compete copepods and ostracods. Cladocerans were the preferred prey of young bluegill (Forsythe, 1978) and only when cladoceran densities were reduced due to predation were *Mesocyclops* and *Physocypria* able to establish sizable populations. The elevated temperature regimens in the present study (+2 C, +4 C, and +6 C) did not cause detectable changes in these predation-competition patterns.

Slight differences in the temporal maxima of some zooplankton populations were noted, but overall the responses of the five dominant populations were remarkably similar with respect to synchrony of density fluctuation as well as magnitudes of population maxima among temperature regimens. Carlson (1974) noted approximate synchronization in population maxima, irrespective of temperature treatments up to 7° C above ambient for *Daphnia ambigua*, *Schpholebris kingi*, and *Ceriodaphnia quadrangula* populations.

Numerous laboratory and field studies have shown that brood-time intervals and maturation times for many zooplankton species are inversely related to environmental temperature. Such findings, however, do not prove that elevated temperatures will necessarily increase zooplankton production

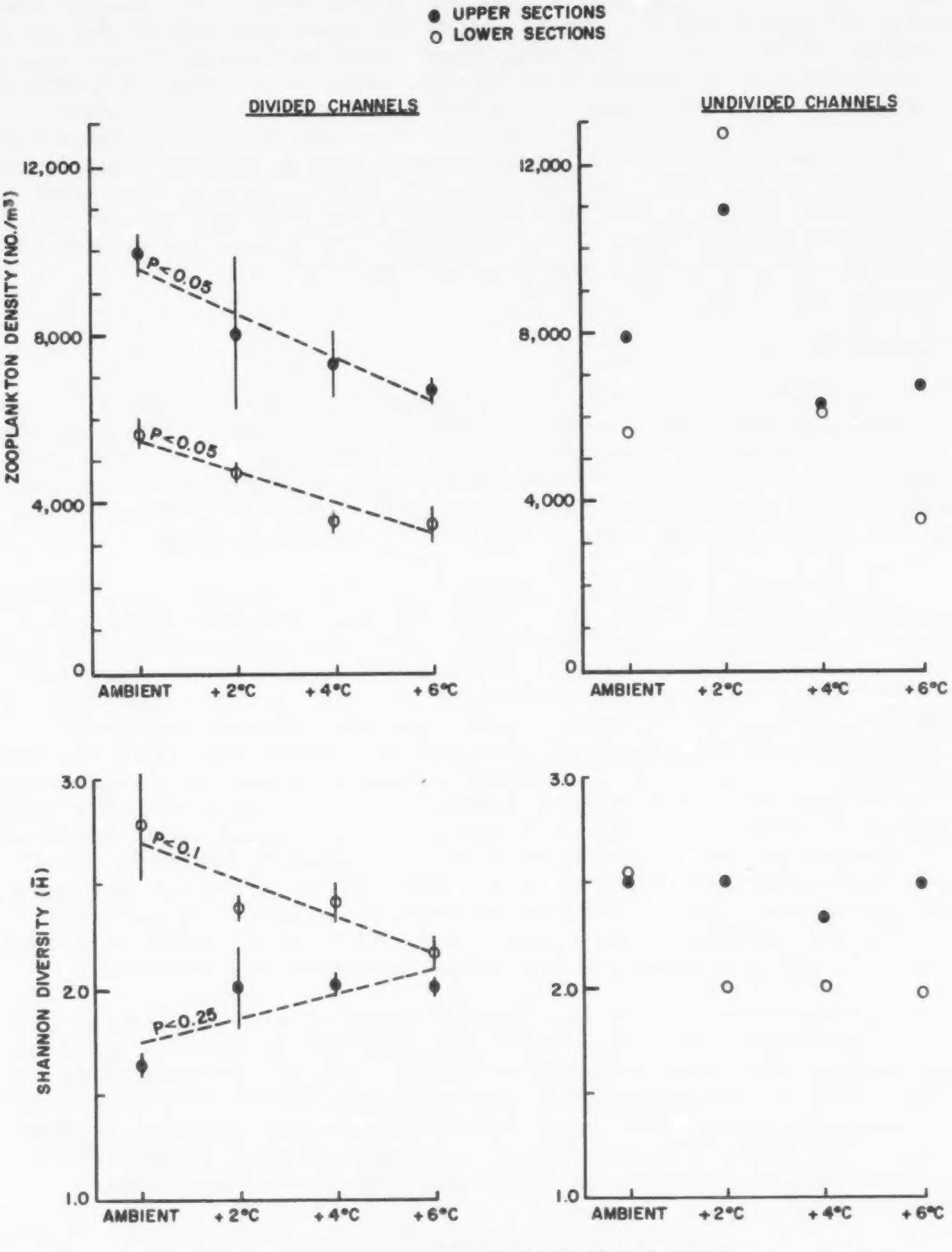

Figure 9. Trends across treatments for mean zooplankton density and mean Shannon diversity, June - August, for upper and lower channel sections of divided and undivided channels.

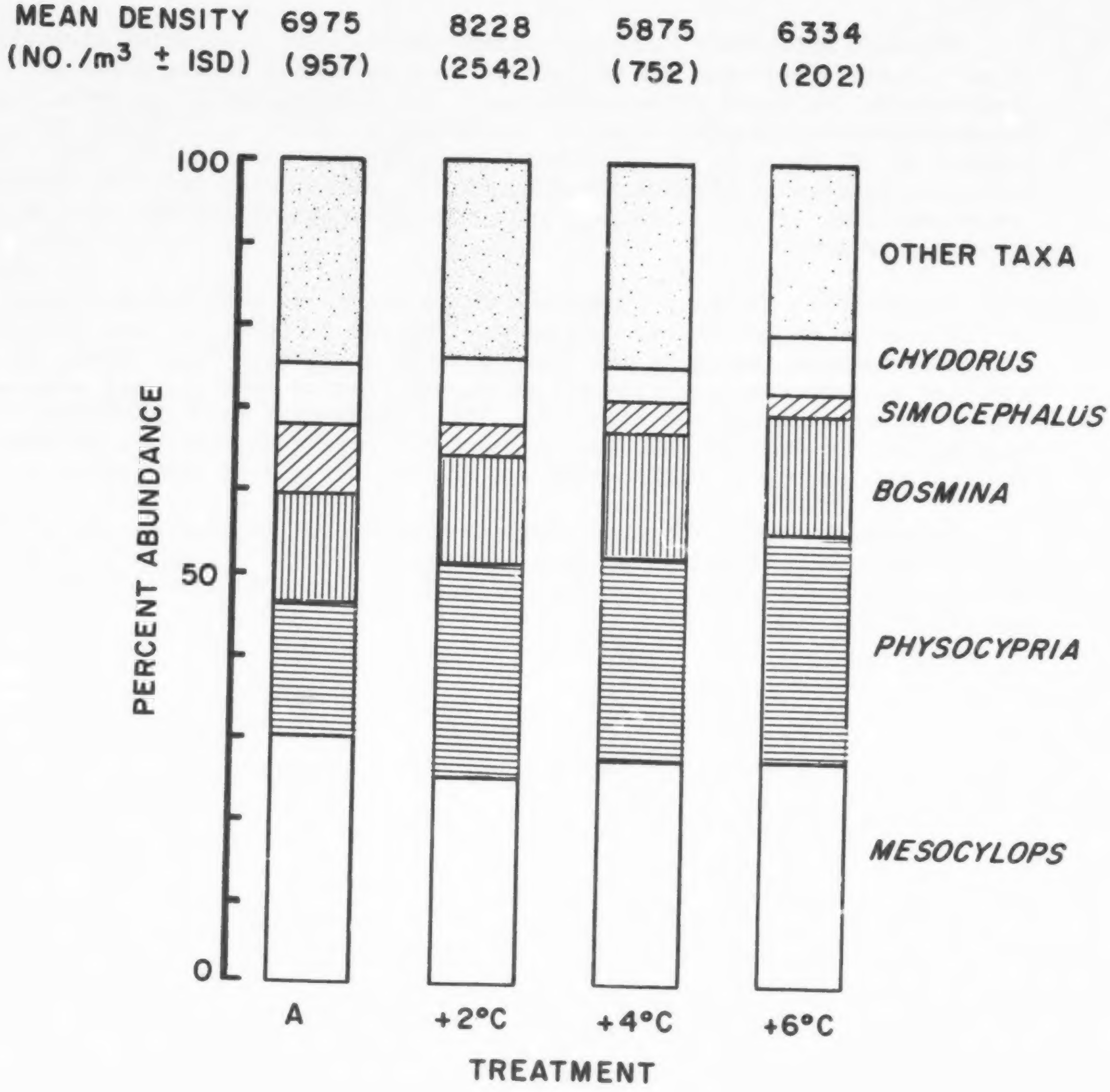

Figure 10. Mean zooplankton density per treatment over the study period and the proportions contributed by the five most abundant taxa.

by increasing population turnover rates. On the contary, some species show decreasing population turnover rates with increasing temperature because of decreased brood sizes (number of eggs) at higher temperatures (Carlson, 1974).

Although this study did not estimate zooplankton production directly, it was hypothesized that any production changes caused by the elevated temperatures, in order to be ecologically significant, would be reflected in young-of-the-year bluegill biomass at the end of the study. Since the biomass of YOY bluegill from the upper sections was not significantly different between treatments (Section 4), any differences in total zooplankton production, if they occurred, were not detected in relation to fish biomass produced.

Dividing two of three channels in each treatment with screens resulted in differences in zooplankton abundance, species composition, and species diversity between the upper and lower channel sections. This result was not expected because the mesh size of the screens should have allowed zooplankton to interchange between sections. The screens must have restricted zooplankton movement to some degree since there were differences between divided and undivided channels for the various parameters studied.

Recommendations for future zooplankton-temperature studies are to use higher temperature treatments, to partition all twelve channels or none at all, to try to separate temperature effects on zooplankton from fish predation impacts.

REFERENCES

Armitage, B. J., T. D. Forsythe, E. B. Rodgers, and W. B. Wrenn. 1978. Browns Ferry Biothermal Research Series I. Colonization by periphyton, zooplankton, and macroinvertebrates. EPA Ecological Research Series, EPA-600/3-78-020, Duluth, MN.

Carlson, D. M. 1974. Responses of planktonic cladocerans to heated waters. *In* Thermal Ecology, J. W. Gibbons and R. R. Sharitz (Eds.), Augusta, GA, 1973, DOE Symposium Series (CONF-730505). pp. 186-206.

Dumont, H. J., I. Vande Velde, and S. Dumont. 1975. The dry weight estimate of biomass in a selection of Cladocera, Copepoda, and Rotifera from the plankton, periphyton, and benthos of continental waters. Oecologia. 19(1): 75-97.

Forsythe, T. D. 1978. Predator-prey interactions among crustacean plankton, young bluegill (*Lepomis macrochirus*), and walleye (*Stizostedion vitreum vitreum*) in experimental ecosystems. Ph.D. Thesis, Michigan State Univ., East Lansing. 98 pp.

Hall, D. J., W. E. Cooper, and E. E. Werner. 1970. An experimental approach to the production dynamics and structure of freshwater communities. Limnol. Oceanogr. 15(6): 839-928.

SECTION 7

MACROINVERTEBRATES

INTRODUCTION

The objective of this phase of the study was to evaluate population and community responses of macroinvertebrates to long-term (185 days) temperature elevations (ca. 2°, 4°, and 6° C above ambient temperatures of the Tennessee River). Because of the unique structure of the experimental system, it was possible to study a naturally colonizing community of organisms simulating that in the Tennessee River. Unlike typical laboratory systems, the biothermal channels contained a wide variety of organisms which were exposed to diurnally and seasonally fluctuating temperature regimens.

Diversity of macroinvertebrates in the biothermal channels is similar to that in large mainstream reservoirs when both deep water and littoral zones are considered. Eight phyla, six classes, and approximately 75 species were identified when colonization was studied in 1974-1975 (Armitage *et al*, 1978). The most abundant organsims were: Oligochaeta, *Corbicula manilensis* (Pelecypoda), *Physa heterostropha* (Gastropoda), *Erpobdella punctata* (Hirudinea), *Hyalella azteca* and *Crangonyx* sp. (Amphipoda), *Caenis* sp. (Ephemeroptera), and Chironomidae (Diptera). Odonates and *Hexagenia bilinea* (Ephemeroptera) were also common as determined from exuviae that were collected from the channel walls and water surfaces.

Sampling was carried out to determine species composition, relative densities and biomass, as well as to provide information on life-cycles, distribution within channels, and inter-specific interactions.

MATERIALS AND METHODS

Macroinvertebrate samples were collected monthly (March-September) in the three habitats of the biothermal channels; pool sediments, limestone rock areas, and wall surfaces. Sampling dates are listed in Table A-1. Pool sediments were sampled with a six-foot length of PVC pipe which was twisted into the substrate to give a core 23.76 cm^2 in area and ca. 12 cm deep. On each sampling date, 12 cores were taken in the upper sections in all channels. On 7 July and 8 August cores were also taken in the lower sections (pool 6).

Rock area samples were collected following 30-day colonization in galvanized trays (0.09 m^2) filled with rock similar to that of the channel rock areas. Three trays were placed in upper channel sections on all dates. On the last three dates, lower sections were sampled as well. Initial treatment of rock tray samples involved gently scrubbing each rock to remove attached organisms. Trays with cleaned rocks were then replaced in channels on the same day they were removed.

Concrete wall surfaces were sampled with a scraping device with attached net which removed algae and associated organisms in a 0.25 m^2 area. Samples were taken in upper sections only in March and April and in both upper and lower sections on all following dates (see Table A-1).

All types of samples were sieved (#70 mesh), and then subsampled in a partitioned plexiglas tray; 0.1 of each sample was retained for analysis. Large organisms (e.g., odonates, large leeches) were not subsampled. All samples or subsamples were frozen immediately and saved for future analysis. Results of analysis of variance of subsamples are given in Table A-2.

Macroinvertebrate organisms were picked from thawed samples and sorted according to taxon. Dominant taxonomic groups from each sample were freeze-dried and then weighed; less abundant groups were only counted. Relative size and maturity of organisms were recorded. Total number of monthly samples were 72 rock trays (24 subsamples), 288 core samples (24 subsamples), and 72 wall scrapings (36 subsamples).

Differences between divided and undivided channels were tested statistically (Mann-Whitney U test, Sokal and Rohlf, 1969). Analysis of variance was performed to detect treatment effects on densities and/or dry weights of individual taxa and the total macroinvertebrate community. When upper channel sections were considered, data from the three habitats were combined according to percent contribution to total area (rock areas, 16%, wall surfaces, 31%, and pool sediments, 53%). In certain cases densities and/or dry weights demonstrated different patterns in different habitats. These variations were analyzed utilizing data from upper and lower sections of all channels.

Biomass diversity and species diversity indices (Shannon-Weaver H^{-1}) were calculated for the three major habitats in each treatment on each sampling date.

When the experiment was terminated the first week of September, 15 adult bluegill from each treatment were dissected and their stomach contents identified and enumerated.

RESULTS

Dominant organisms in terms of numbers and/or biomass provided the basis for statistical evaluation of temperature effects. These were the same taxa which were dominant as the channels were colonized under ambient temperature conditions (Armitage et al., 1978). They were Gastropoda, especially *Physa heterostropha*, *Lymnaea* sp., and *Pyrgulopsis letsoni*; Hirudinea, including *Placobdella montifera*, *Helobdella* sp., and *Eropbdella punctata*; Amphipoda, including *Crangonyx* sp., and *Hyalella azteca*; *Caenis* sp. (Ephemeroptera); Libellulidae, and *Enallagma civile* (Odonata), and Chironomidae.

In the comparison of divided and undivided channels in pool areas, there were no significant differences seen on any date (Table 14). There were not enough samples available for analysis on March 30. On August 31, in rock areas only, *Caenis* sp. showed a significant difference ($P < 0.05$) when it's dry weight was greater in undivided channels (Table 15). On three dates early in the study there were not enough samples available for the test used. On wall surfaces, *Caenis* sp. had significantly greater biomass in divided channels ($P < 0.05$) on June 6 and August 2 (Table 16). Total macroinvertebrates, exclusive of Mollusca, had greater dry weight ($P < 0.05$) in divided than in undivided channels. Because the spatial distribution of dominant organisms in the experimental channels was almost completely uninfluenced by presence of screen barriers used to divide fish populations, the statistics presented were gathered on data from both divided and undivided channels. Analyses of biomass and densities in upper sections are emphasized here because they represented effects of the highest temperatures in the channels.

Total Macroinvertebrates

Biomass of total macroinvertebrates, excluding Mollusca, was quite evenly distributed in the channels despite the presence of screen barriers. Only in the August 2 wall scrapings was there greater biomass ($P < 0.05$) in divided than in undivided channels (Table 16).

A list of organisms included in the category "total macroinvertebrates" appears in Table A-4. See also Armitage *et al*., 1978, for a list of species which colonized the channels in 1974-1976.

Peak dry weight of total macroinvertebrates, exclusive of Mollusca, occurred in all but the +2 C treatment in early May (Table 17, Fig. 12). The +4 C channels had the greatest biomass at this time (ca. 5 gm m^{-2}) although it was not significantly different from that in other treatments. Temperatures in +4 C channels had increased from 19° to 25° C during the preceding month. The +2 C channels did not attain maximum biomass until early June (ca. 2 gm m^{-2}) following a temperature increase from 21° to 28° C the preceding month. At this time, +2 C channel biomass was significantly greater than that in both ambient and +4 C channels ($P \leq 0.05$). Ambient channels demonstrated a second biomass peak (ca. 1.6 gm m^{-2}) beginning in July when the temperature had increased to about 30° C from 26° C the previous month. Both ambient and +2 C treatments had significantly greater dry weights ($P \leq 0.05$) than that of +4 C channels in July. On the final sampling date in August, dry weight in ambient channels (ca. 1.8 gm m^{-2}) exceeded that in both +4 C and +6 C channels ($P \leq 0.05$). Ambient and +6 C channel temperatures had decreased from 30° to 28° C and 34.5° to 34° C, respectively, since early July.

Dry weight of total macroinvertebrates, excluding Mollusca, varied between habitats. Wall surfaces had the least biomass, ranging up to only

TABLE 14. COMPARISON OF DIVIDED AND UNDIVIDED CHANNELS.* POOL SEDIMENTS.

Organism	Mar. 30†	May 6	Jun. 10	Jul. 7	Aug. 8
Caenis (mg m^{-2})			N.S.	N.S.	N.S.
Chironomidae (mg m^{-2})		N.S.	N.S.	N.S.	N.S.
Amphipoda (mg m^{-2})			N.S.	N.S.	
Libellulidae (mg m^{-2})					
Hirudinea (mg m^{-2})		N.S.	N.S.	N.S.	
Total Gastropoda (no m^{-2})		N.S.	N.S.	N.S.	N.S.
Total Macroinvertebrates minus Mollusca					
mg m^{-2}		N.S.	N.S.	N.S.	N.S.
no m^{-2}		N.S.	N.S.	N.S.	N.S.

* Above weir divided channels compared with whole undivided channels Mann-Whitney U test.

† Too few samples for statistical analysis.

TABLE 15. COMPARISON OF DIVIDED AND UNDIVIDED CHANNELS.* ROCK AREAS.

Organism	Mar 30	Apr 27†	May 11†	May 31†	Jun 28	Jul 28	Aug 31
Caenis ($mg\ m^{-2}$)	N.S.				N.S.	N.S.	u $P < 0.05$
Chironomidae ($mg\ m^{-2}$)	N.S.				N.S.	N.S.	N.S.
Amphipoda ($mg\ m^{-2}$)	N.S. N.S.				N.S.	N.S.	N.S.
Hirudinea ($mg\ m^{-2}$)	N.S.				N.S.	N.S.	N.S.
Enallagma ($mg\ m^{-2}$)	N.S.				N.S.		
Libellulidae ($mg\ m^{-2}$)	N.S.				N.S.	N.S.	N.S.
Total Gastropoda ($no\ m^{-2}$)	N.S.				N.S.	N.S.	N.S.
Total Macroinvertebrates minus Mollusca							
$mg\ m^{-2}$	N.S.				N.S.	N.S.	N.S.
$no\ m^{-2}$	N.S.				N.S.	N.S.	N.S.

* Upper divided channels compared with whole undivided channels
Mann-Whitney U test

† Too few samples for statistical analysis

u Undivided greater

TABLE 16. COMPARISON OF DIVIDED AND UNDIVIDED CHANNELS.* WALLS.

Organism	Mar 2	Apr 5	May 1	Jun 6	Jul 1	Aug 2	Sep 2
Caenis ($mg\ m^{-2}$)	N.S.	N.S.	N.S.	d $P < 0.05$	N.S.	d $P < 0.05$	N.S.
Chironomidae ($mg\ m^{-2}$)	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
Amphipoda ($mg\ m^{-2}$)	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
Libellulidae ($mg\ m^{-2}$)	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
Total Gastropoda ($no.\ m^{-2}$)	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
Total Macroinvertebrates minus Mollusca							
$mg\ m^{-2}$	N.S.	N.S.	N.S.	N.S.	N.S.	d $P < 0.05$	N.S.
$no.\ m^{-2}$	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.

* Upper divided channels compared with whole undivided channels
Mann-Whitney U test

d Divided greater

TABLE 17. ANOVA OF TREATMENT EFFECTS ON DRY WEIGHT (mg m^{-2}) OF TOTAL MACROINVERTEBRATES (EXCLUDING MOLLUSCA).†

	A	+2 C	+4 C	+6 C	DF	Error S.S.	Error M.S.	Treatment Effects§
Apr*	1726	381	1024	865				
May	2255	805	5063	3133	8	2.4431	0.3053	
Jun	588	1921	920	1363	8	0.1866	0.0233	+2 > +4 = A, +6 > A
Jul	1564	1792	337	503	8	0.6635	0.0829	A = +2 > +4
Aug	1799	564	464	314	8	0.4569	0.0571	A > +4 = +6

† Performed on log-transformed means (three replicates) using least significant differences (Sokal and Rohlf, 1969).

§ $P \leq 0.05$.

* Too few samples for analysis.

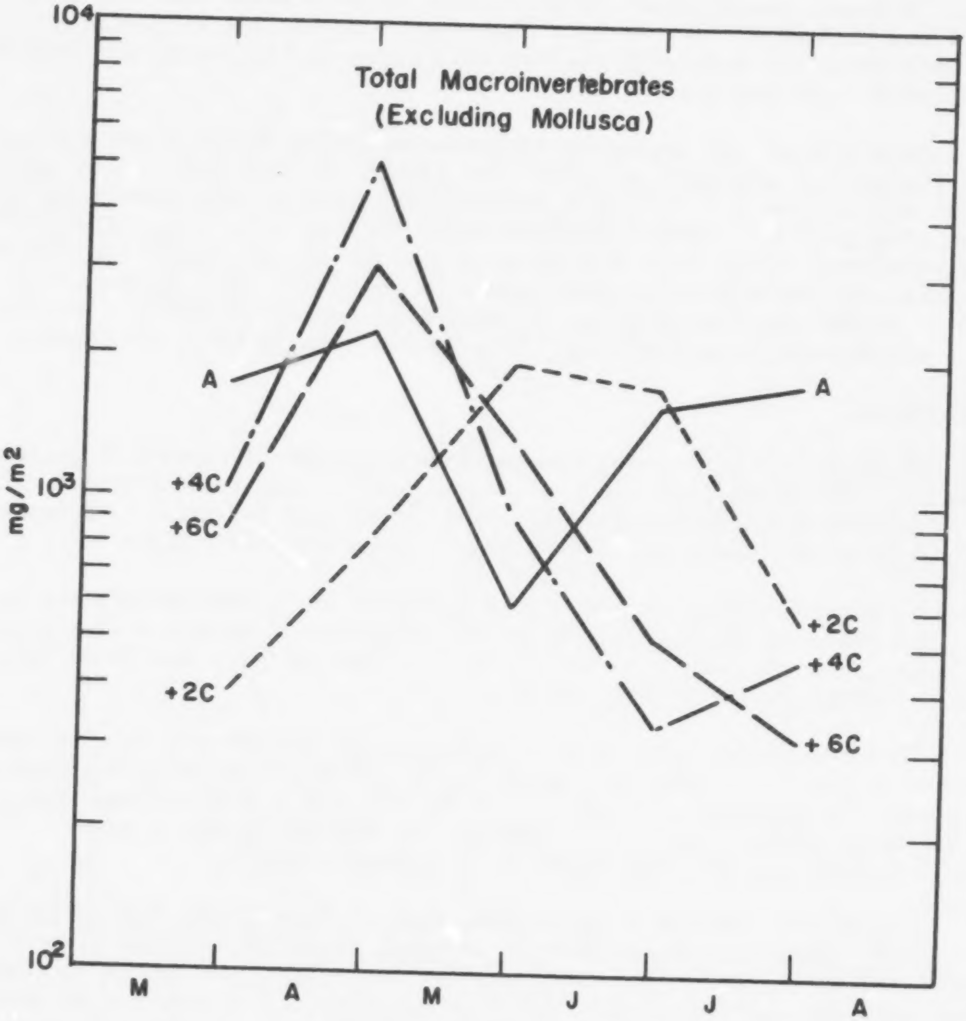

Figure 12. Monthly mean dry weight of total macroinvertebrates excluding Mollusca in four temperature treatments (three channels per treatment): A (ambient temperature of Wheeler Reservoir, Tennessee River), and +2°, +4°, and +6° C above ambient.

394 mg m^{-2} in ambient channels in July. Final samples taken in early September did not exceed 75 mg m^{-2} in any treatment (Fig. 13, Table A-3). Biomass in pool areas generally exceeded that in both rock and wall areas, especially in ambient and +2 C regimens. The greatest biomass in pool areas was estimated in +4 C (ca. 4.5 gm m^{-2}) and +6 C (ca. 8.3 gm m^{-2}) channels in May. However, these values were exceeded in rock areas (ca. 9.8 gm m^{-2} in +4 C and 16.3 gm m^{-2} in the +6 C channels). At the end of the study, biomass in pool areas was greatest; that on wall surfaces was least, and that on rock areas intermediate.

Densities of all macroinvertebrates including Mollusca peaked in all but the ambient channels in early June (Table 18, Fig. 14). Both the +2 C (9740 m^{-2}) and +4 C (11973 m^{-2}) channels had greater macroinvertebrate densities than did ambient channels (5838 m^{-2}) at this time. The +2 C peak continued into early July when both it and the ambient value (ca. 10000 m^{-2}) were significantly greater than densities in +4 and +6 C channels (ca. 3000 m^{-2}). August macroinvertebrate densities in ambient channels (16167 m^{-2}) were significantly greater than those in the three warmest treatments.

Gastropoda

Physa heterostropha was the numerically dominant gastropod in most samples, with *Pyrgulopsis letsoni* occasionally being more numerous. *Lymnaea* sp. maintained sparse populations until August and September; *Pleurocera* sp. and *Helisoma* sp. were only infrequently collected (Table A-4).

P. heterostropha densities were examined for treatment effects in terms of both combined and separate habitats. Results of analysis of treatment effects (separate habitats) on *P. letsoni*, *Lymnaea* sp., and total Gastropoda are presented in Tables A-5 through A-8.

P. heterostropha densities ranged between ca. 150 m^{-2} in +6 C channels in May and +2 C channels in August, to ca. 2400 m^{-2} in ambient channels in May and +2 C channels in June (Table 19, Fig. 15). A treatment effect was noted only in May, when *Physa* densities in ambient channels were significantly greater than those in any other channel.

Effects of temperature elevation on *P. heterostropha* varied among habitats. Peak deinsities in rock and wall areas (ca. 3000 m^{-2}) occurred in April and May in all treatments; populations in the pool areas increased only upon the decline of wall and rock populations in late May to June except in the +6 C treatment (Fig. 16). In the +6 C channels *P. heterostropha* populations on rock areas increased simultaneously with those in pools and attained similar peaks (ca. 1200 m^{-2}).

Amphipoda

Two amphipod species, *Hyalella azteca* and *Crangonyx* sp., were present; these were lumped together for consideration of amphipod dry weight. In only the ambient and +2 C channels did amphipod biomass increase following the beginning of sampling in April (Table 20, Fig. 17). These channels attained peaks of 155 mg m^{-2} in early June (+2 C) and July (ambient).

Figure 13. Monthly mean dry weight of total macroinvertebrates excluding Mollusca in three habitats (rocks, walls, pools) and four temperature treatments (three channels per treatment): A (ambient temperature of Wheeler Reservoir, Tennessee River), an +2°, +4°, and +6° C above ambient.

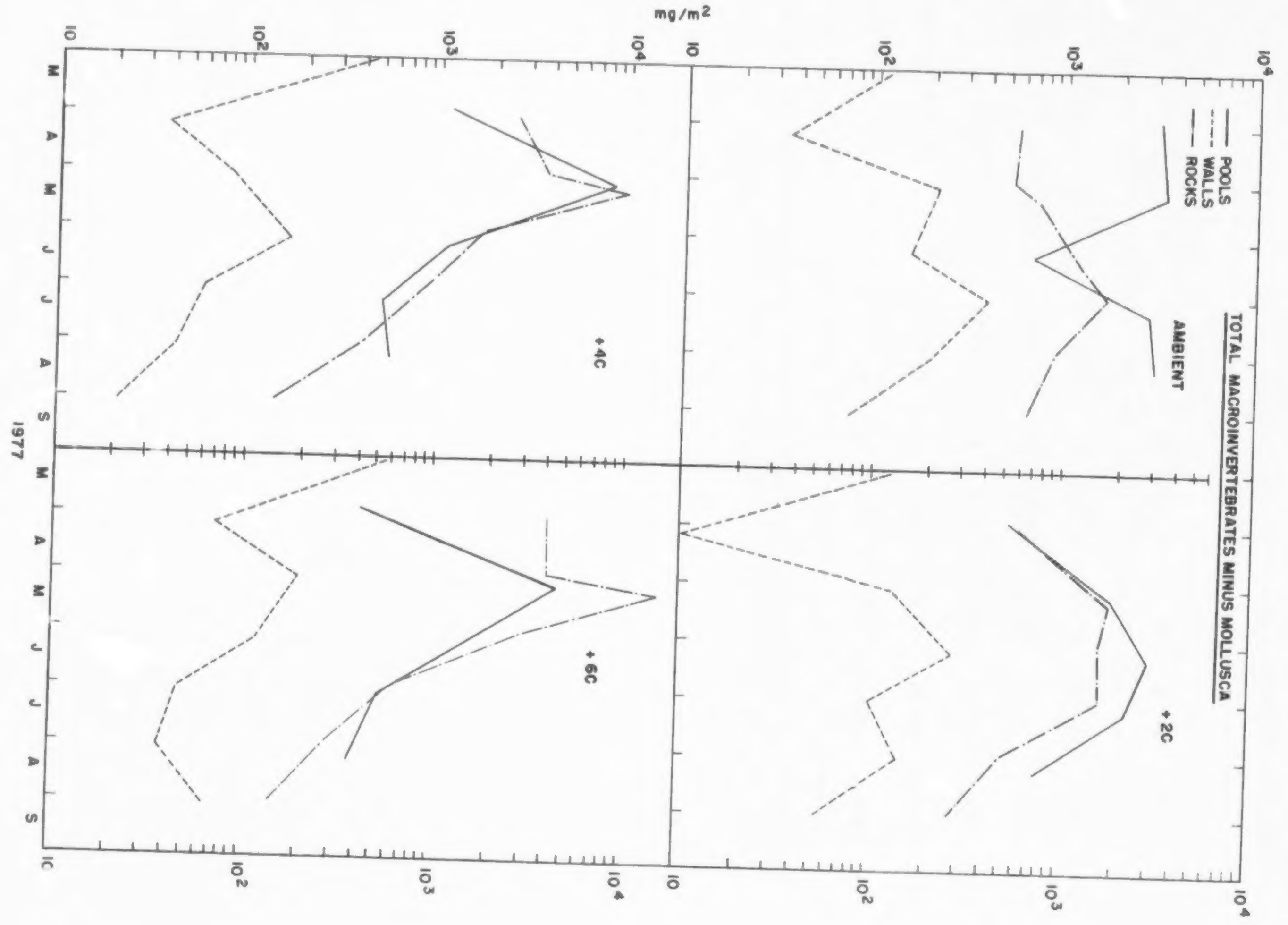

TABLE 18. ANOVA OF TREATMENT EFFECTS ON MEAN DENSITY (no m^{-2}) OF TOTAL MACROINVERTEBRATES INCLUDING MOLLUSCA.†

	A	+2 C	+4 C	+6 C	DF	Error S.S.	Error M.S.	Treatment Effects§
Apr	1897	1478	1849	1249	8	0.8118	0.1014	
May	6103	3804	5545	3045	8	0.2836	0.0354	
Jun	5838	9740	11973	7553	8	0.0781	0.0097	+2 = +4 > A
Jul	10142	9909	3430	3167	8	0.3903	0.0487	A = +2 > +4 = +6
Aug	16167	6083	4078	2250	8	0.3996	0.0499	A > +2 = +4 = +6

† Performed on log-transformed means (three replicates) using least significant differences (Sokal and Rohlf, 1969).

§ $P \leq 0.05$.

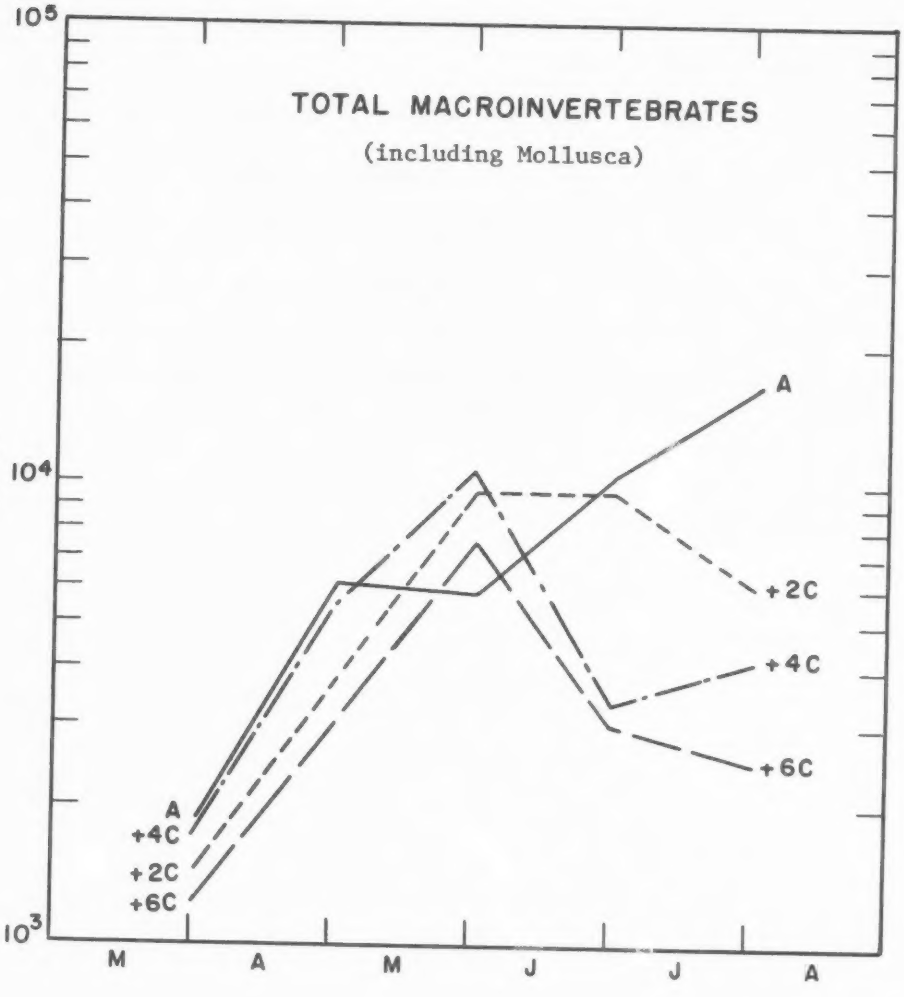

Figure 14. Monthly mean density of total macroinvertebrates including Mollusca in four temperature treatments (three channels per treatment): A (ambient temperature of Wheeler Reservoir, Tennessee River), and +2°, +4°, and +6° C above ambient.

TABLE 19. ANOVA OF TREATMENT EFFECTS ON MEAN DENSITY (no m^{-2}) OF *PHYSA HETEROSTROPHA*.†

	A	+2 C	+4 C	+6 C	DF	Error S.S.	Error M.S.	Treatment Effects§
Apr*	689	1469	589	478				
May	2457	523	806	151	8	0.5635	0.0704	A > +2 = +4 = +6
Jun	1957	2355	1977	563	8	2.8458	0.3557	
Jul	1223	385	470	961	8	3.1128	0.3891	
Aug	1145	157	373	280	8	2.0851	0.2606	

† Performed on log-transformed means (three replicates) using least significant differences (Sokal and Rohlf, 1969).

§ $P \leq 0.05$.

* Too few samples for analysis.

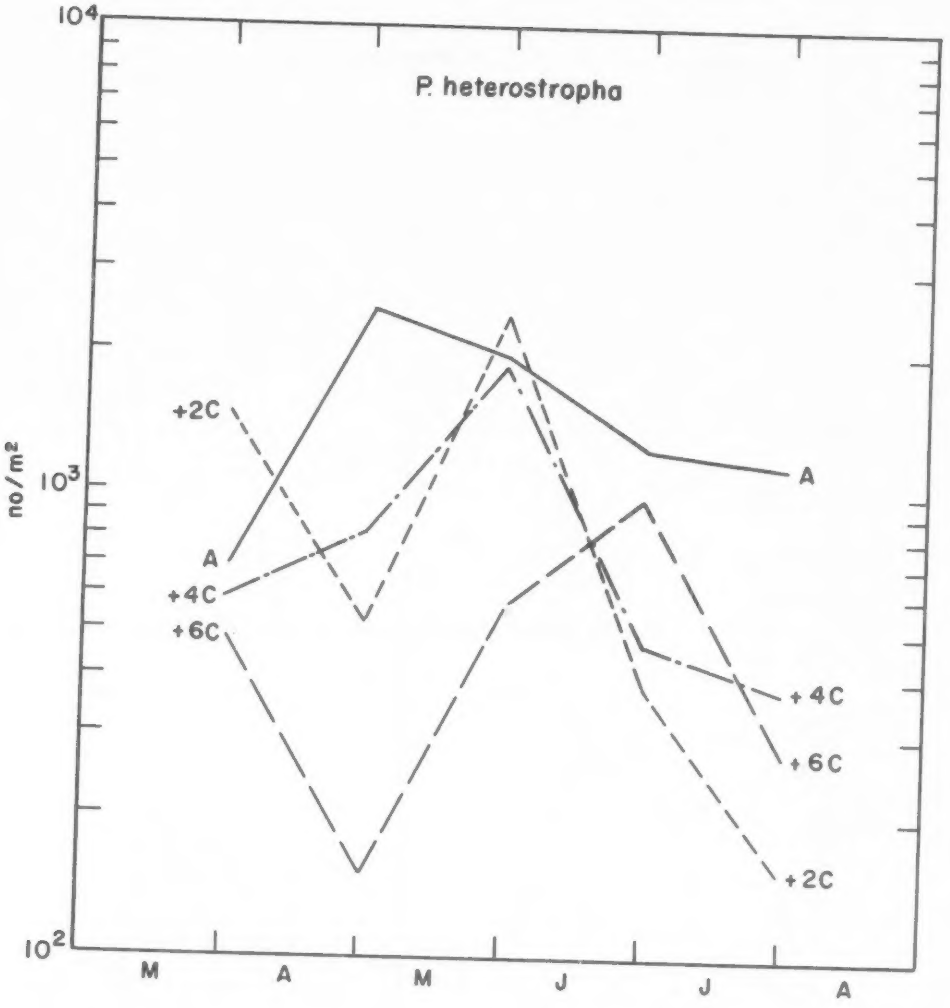

Figure 15. Monthly mean density of *Physa heterostropha* in four temperature treatments (three channels per treatment): A (ambient temperature of Wheeler Reservoir, Tennessee River), and +2°, +4°, and +6° C above ambient.

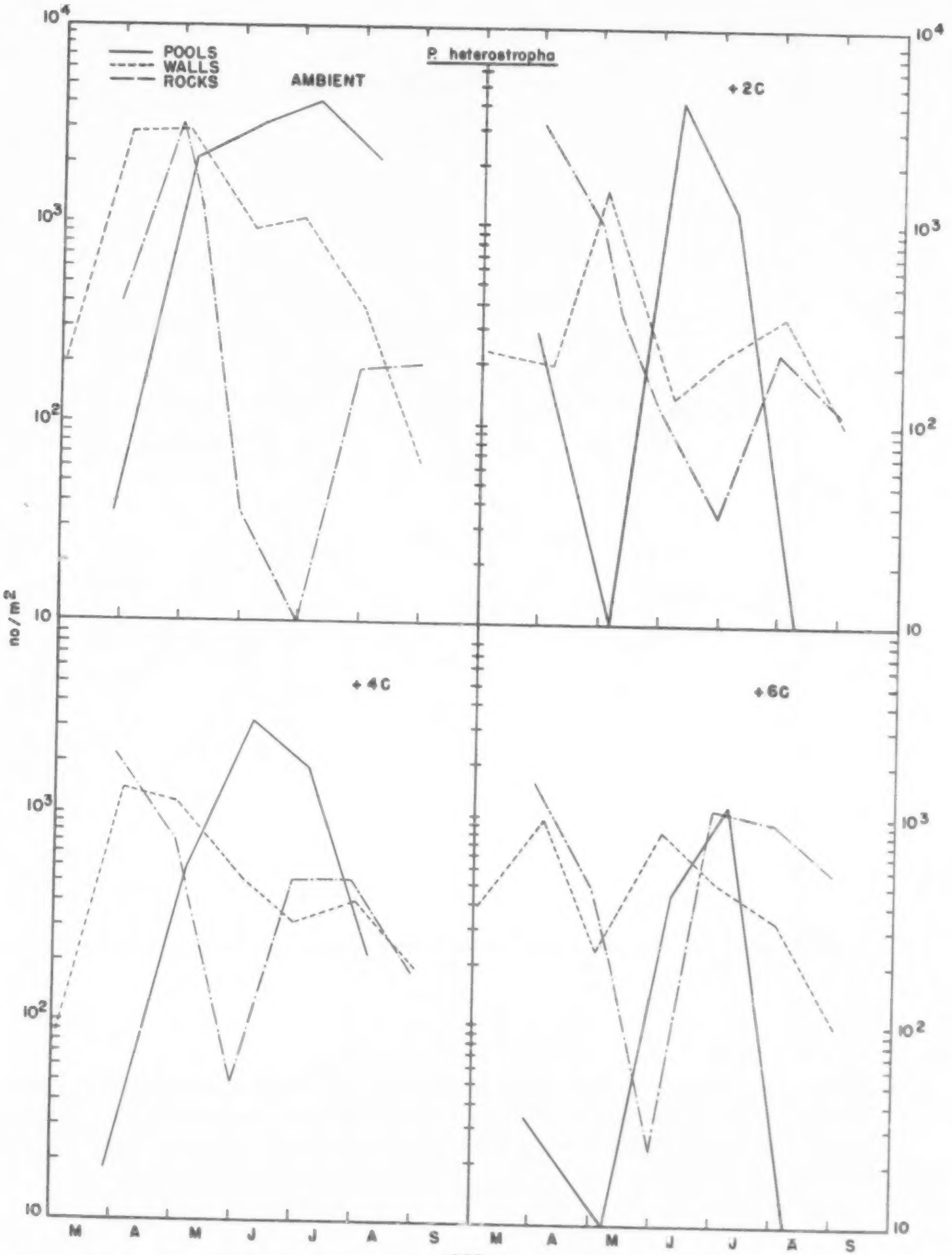

Figure 16. Monthly mean density of *Physa heterostropha* in three habitats (rocks, walls, pools) and four temperature treatments (three channels per treatment): A (ambient temperature of Wheeler Reservoir, Tennessee River), and +2°, +4°, and +6° C above ambient.

TABLE 20. ANOVA OF TREATMENT EFFECTS ON DRY WEIGHT (mg m^{-2}) OF AMPHIPODA.†

	A	+2 C	+4 C	+6 C	DF	Error S.S.	Error M.S.	Treatment Effects§
Apr	6	30	138	38	8	3.9847	0.498	
May	58	120	140	25	8	1.5633	0.1954	+2 = +4 > +6
Jun	49	153	73	30	8	0.5413	0.0676	+2 > A = +6
Jul	160	117	10	2	8	1.2187	0.4062	A = +2 > +4 = +6
Aug	14	0	0	0	8	0.6754	0.0844	A > +2 = +4 = +6

† Performed on log-transformed means (three replicates) using least significant differences (Sokal and Rohlf, 1969).

§ $P \leq 0.05$.

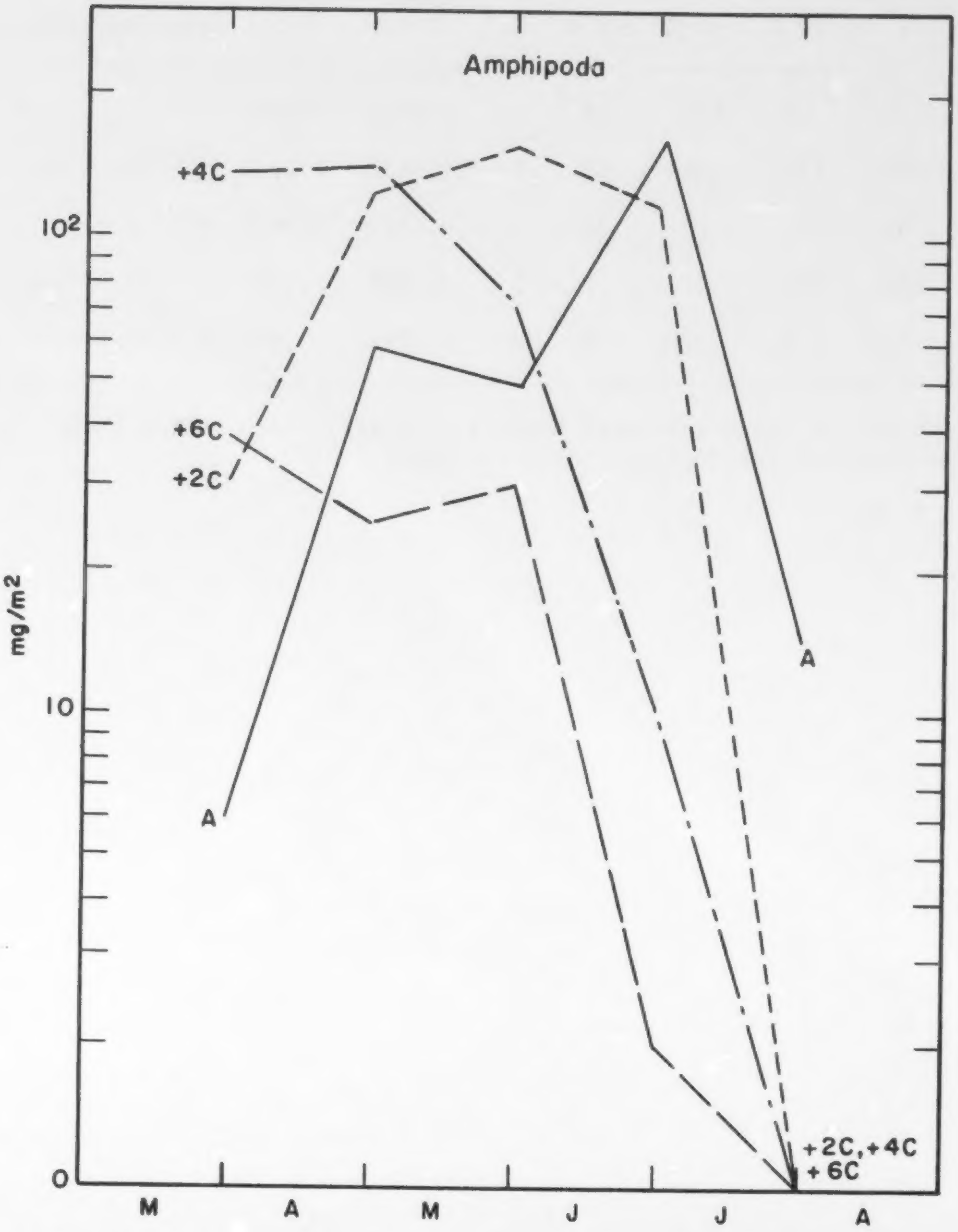

Figure 17. Monthly mean dry weight of Amphipoda in four temperature treatments (three channels per treatment): A (ambient temperature of Wheeler Reservoir, Tennessee River), and +2°, +4°, and +6° C above ambient.

Amphipod biomass in the +4 C channels dropped from a maximum of 140 mg m^{-2} in April and early May to zero in August; the +6 C channel values dropped from 38 mg m^{-2} in early April to zero in August.

Expected treatment effects became obvious beginning in early July when both ambient and +2 C channels had significantly greater amphipod biomass than did the two warmest temperatures ($P \leq 0.05$) (Table 20). At this time, temperatures had increased from 27° to 32° C in the +4 C channels from 30° to 34.5° C in the +6 C channels during the preceding month. By early August only ambient channels had amphipod populations (ca. 14 mg m^{-2}).

Total amphipod densities ranged to 3176 m^{-2} in ambient channels in early June (Table 21, Fig. 18). As was true for biomass, in only the ambient and +2 C channels did amphipod densities increase after the beginning of the study. Densities in +4 C channels dropped from 1290 m^{-2} in April to zero in August; those in +6 C channels dropped from 208 m^{-2} to zero.

Expected treatment effects appeared in early May when +6 C channels had smaller amphipod populations than any other treatment. By August, ambient channel amphipod densities were greater than those in +2 C channels, which were in turn greater than those in either +4 or +6 C channels.

The sharpest decreases in +4 and +6 C channel amphipod density and biomass occurred in June when temperatures were between 27° and 32° C, and between 30° and 34° C, respectively. Previously, slight decreases in +6 C populations had occurred at temperatures of 25° to 30° C. The sharpest decreases in ambient and +2 C amphipod density and biomass followed in July at temperatures decreasing from 30° to 28° C and from 32° to 30° C, respectively. Slight decreases in +2 C populations had begun a month earlier at temperatures of 27° to 31° C.

H. azteca and *Crangonyx* sp. densities considered speparately illustrate the relatively earlier decline of *Crangonyx* populations in all treatments (Tables 22 and 23). Also, *Crangonyx* populations in the ambient and +2 C channels did not increase after May as did those of *Hyalella*. Treatment effects on these two species were similar to those on the whole amphipod populations.

Response of amphipod density to increased temperature varied between habitats. In the ambient regimen, amphipods reached their peak abundance in pool areas (3507 m^{-2} in July). Those in rock and wall areas were between 1000 and 2000 m^{-2} at the same time (Fig. 19, Table A3). In all the heated regimens, amphipod densities were greatest in rock areas until late July and August when they were exceeded by those along walls. In the +6 C channels, amphipods were never present in pool areas.

Ephemeroptera

Caenis sp. was the dominant ephemeropteran during the study; *Hexagenia bilineata* was only occasionally collected. *Caenis* had two emergence periods as evidenced by declines in density and biomass (Figs. 20 and 21); these declines were supported by observations of numerous final nymphal exuviae on

TABLE 21. ANOVA OF TREATMENT EFFECTS ON MEAN DENSITY (no m^{-2}) OF AMPHIPODA.†

	A	+2 C	+4 C	+6 C	DF	Error S.S.	Error M.S.	Treatment Effects§
Apr	75	275	1290	208	8	2.2484	0.2810	+4 > A
May	343	762	670	191	8	0.5575	0.0696	A = +2 = +4 > +6
Jun	1123	703	439	179	8	0.6621	0.0827	A = +2 = +4 > +6
Jul	3167	759	76	15	8	1.0651	0.1331	A = +2 > +4 > +6
Aug	331	21	0	0	8	0.7620	0.0952	A > +2 > +4 = +6

† Performed on log-transformed means (three replicates) using least significant differences (Sokal and Rohlf, 1969).

§ $P \leq 0.05$.

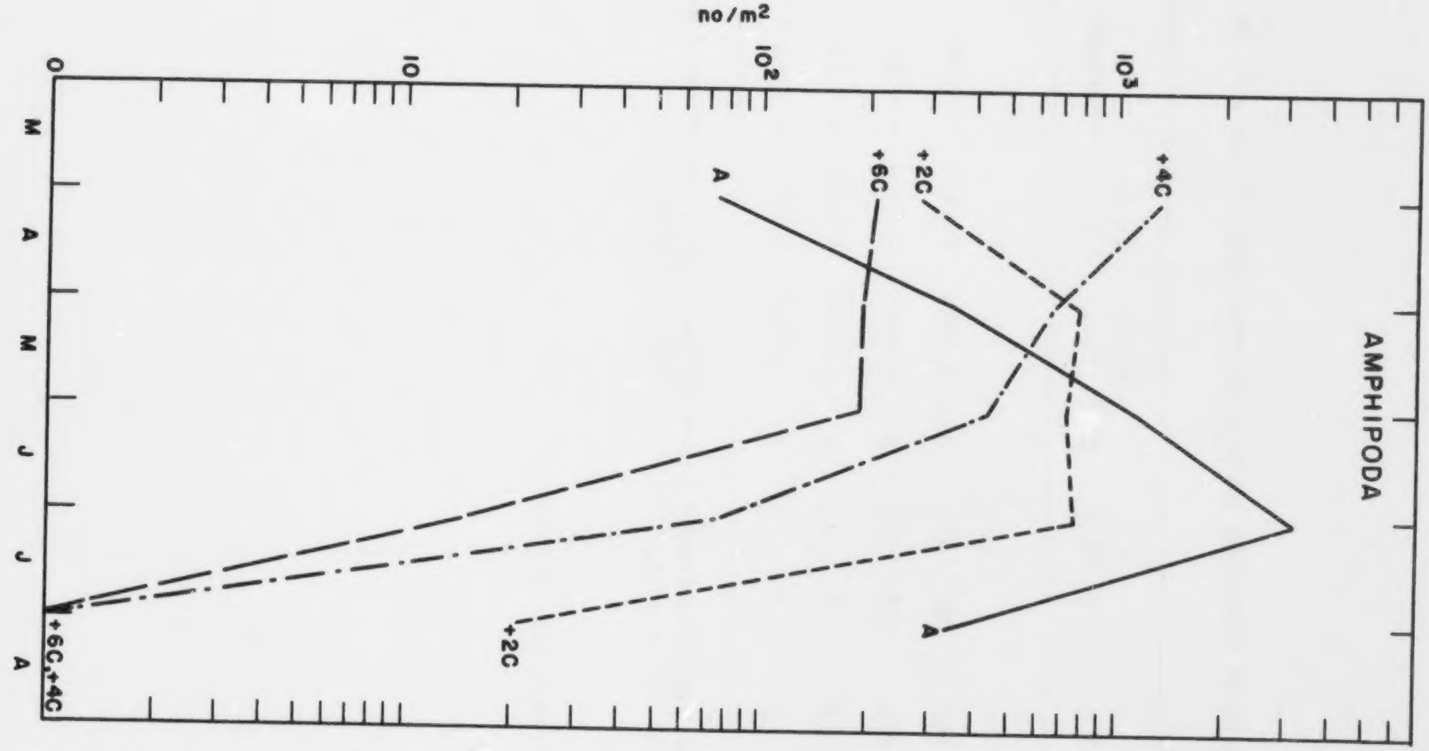

Figure 18. Monthly mean density of Amphipoda in four temperature treatments (three channels per treatment): A (ambient temperature of Wheeler Reservoir, Tennessee River), and +2°, +4°, and +6° C above ambient.

TABLE 22. ANOVA OF TREATMENT EFFECTS ON MEAN DENSITY (no m^{-2}) OF *HYALELLA AZTECA*.†

	A	+2 C	+4 C	+6 C	DF	Error S.S.	Error M.S.	Treatment Effects†
Apr*								
May	232	569	363	111	8	1.1480	0.1435	+2 > +6
Jun	1071	621	357	131	8	0.8849	0.1106	A = +2 > +6
Jul	3112	655	76	15	8	1.1670	0.1458	A = +2 > +4 > +6
Aug	279	21	0	0	8	0.8123	0.1015	A > +2 > +4 = +6

† Performed on log-transformed means (three replicates) using least significant differences (Sokal and Rohlf, 1969).

§ $P \geq 0.05$.

* Too few samples for analysis.

TABLE 23. ANOVA OF TREATMENT EFFECTS ON MEAN DENSITY (no m^{-2}) OF *CRANGONYX* SP.†

	A	+2 C	+4 C	+6 C	DF	Error S.S.	Error M.S.	Treatment Effects§
Apr*								
May	102	190	306	84	8	1.6796	0.2099	
Jun	52	79	78	6	8	1.8656	0.2332	A = +2 = +4 > +6
Jul	55	4	0	0	8	0.7326	0.0915	A > +2 > +4 = +6
Aug	48	0	0	0	8	0.4746	0.0593	A > +2 = +4 = +6

† Performed on log-transformed means (three replicates) using least significant differences (Sokal and Rohlf, 1969).

§ $P \leq 0.05$.

* Too few samples for analysis.

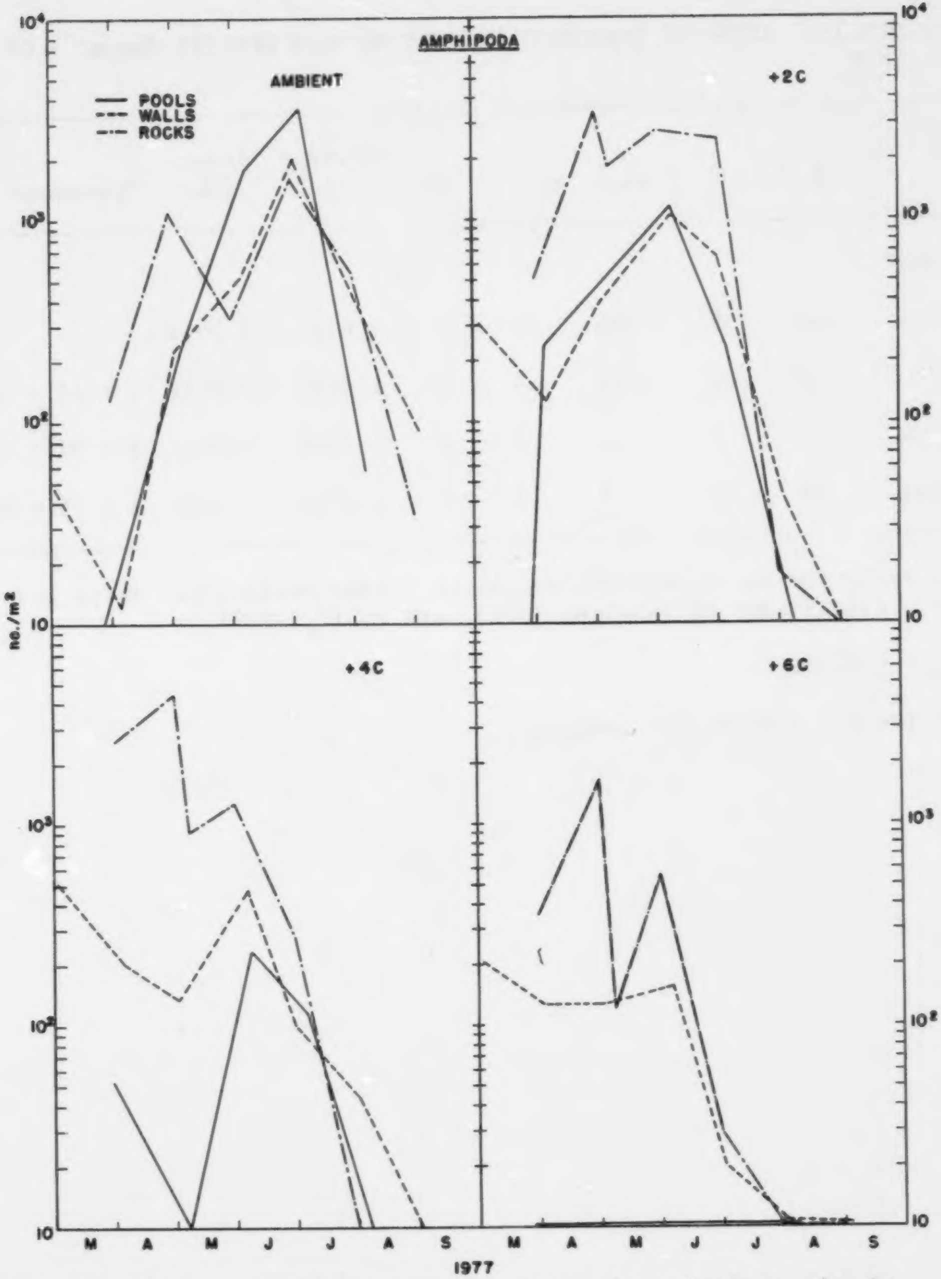

Figure 19. Monthly mean density of Amphipoda in three habitats (rocks, walls, pools) and four temperature treatments (three channels per treatment): A (ambient temperature of Wheeler Reservoir, Tennessee River), and +2°, +4°, and +6° C above ambient.

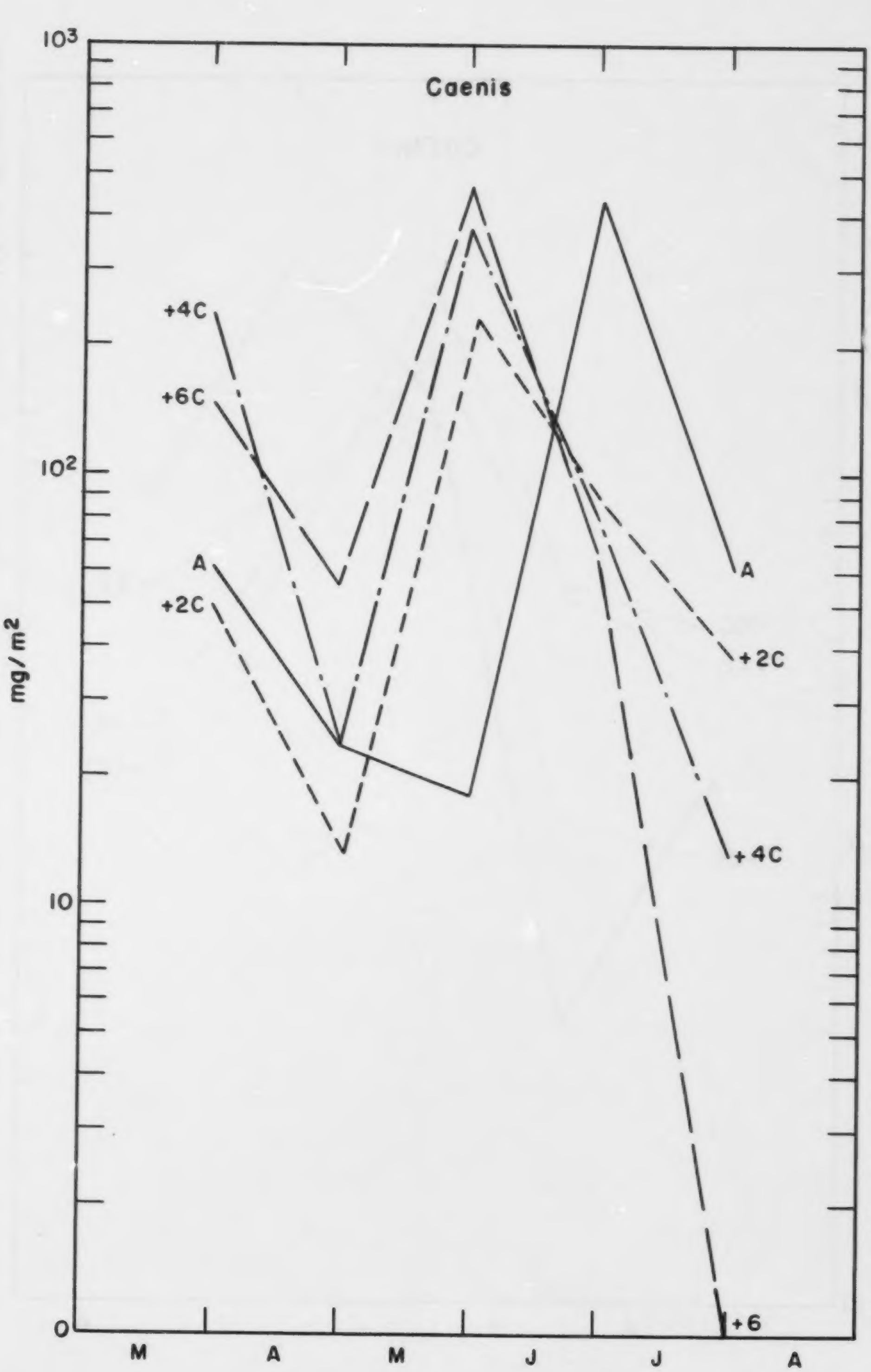

Figure 20. Monthly mean dry weight of *Caenis* sp. in four temperature treatments (three channels per treatment): A (ambient temperature of Wheeler Reservoir, Tennessee River), and +2°, +4°, and +6° C above ambient.

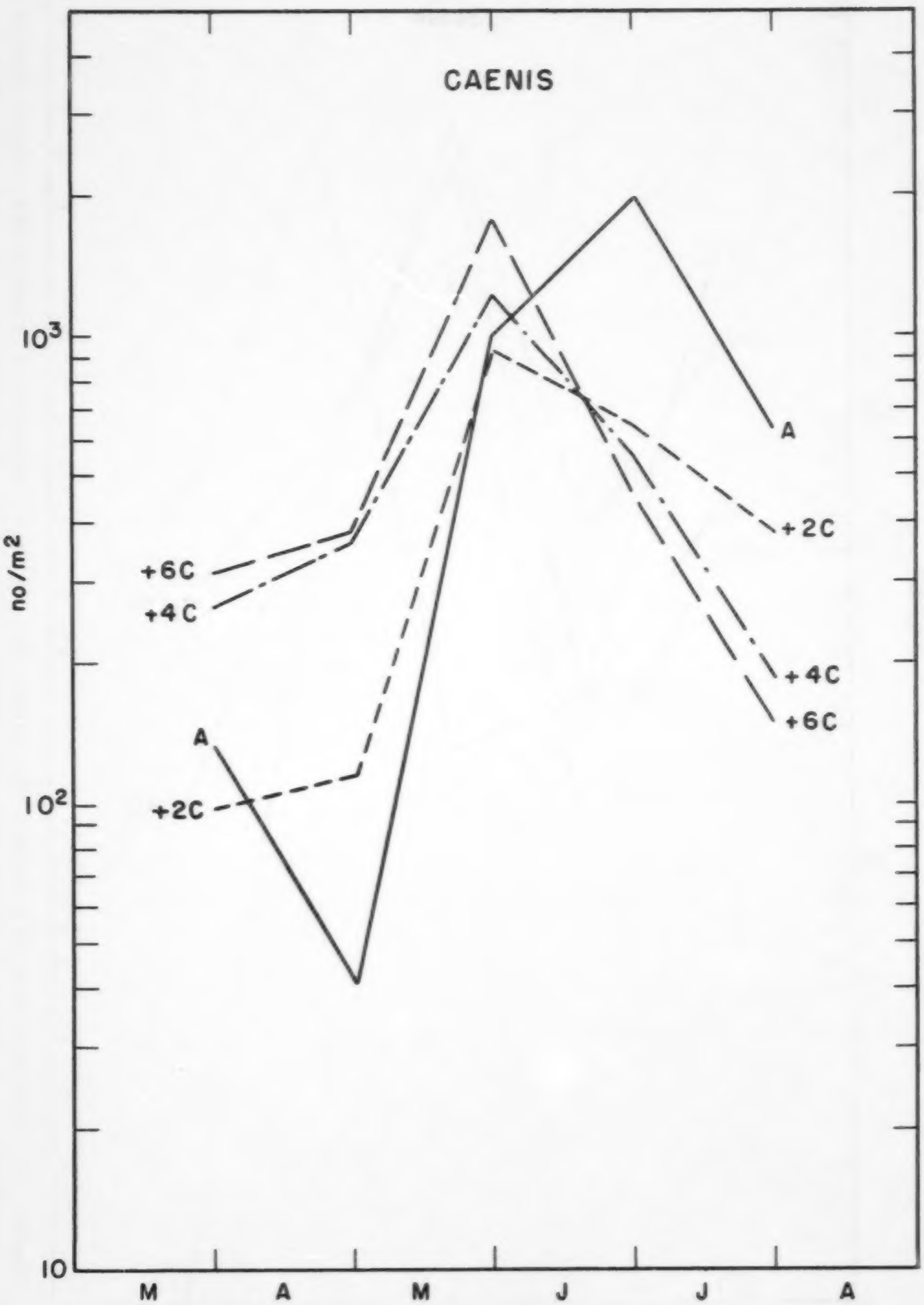

Figure 21. Monthly mean density of *Caenis* sp. in four temperature treatments (three channels per treatment): A (ambient temperature of Wheeler Reservoir, Tennessee River), and +2°, +4°, and +6° C above ambient.

water surfaces. The first emergence occurred in April in all treatments when dry weights declined from a maximum of 238 mg m^{-2} in +4 C channels, to an early May maximum of 55 mg m^{-2} in +6 C channels (Table 24). In early May this +6 C *Caenis* biomass was significantly greater than that in the +2 C channels. *Caenis* densities declined only in the ambient channels in April (Table 25, Fig. 21). Peak *Caenis* biomass and density were attained in the three warmest temperature regimens in early June (225-460 mg m^{-2}, 950-1170 m^{-2}); these channels had greater dry weight and +6 C channels greater density than did ambient channels ($P \leq 0.05$) at that time. Temperatures in the +2, +4, and +6 C treatments had increased from 20° to 28° C, from 21° to 29° C, and from 22° to 30° C, respectively. After a temperature increase from 20° to 25.5° C in early June, ambient *Caenis* did not evidence a mid-summer peak until early July (425 mg m^{-2}, 1943 m^{-2}). There were no significant treatment effects detected at this time. In August, at the end of the study, the biomass of *Caenis* (61 mg m^{-2}) in the ambient regimen was signifcantly greater than that in the +6 C regimen (1 mg m^{-2}) with the +2 C and +4 C channels having intermediate biomass. In August *Caenis* densities in ambient channels (632 m^{-2}) were greater than those in both +4 C and +6 C channels (ca. 175 m^{-2}).

Declines in density, indicating emergence, occurred at different times in different habitats and temperature treatments (Figs. 22 through 24). *Caenis* densities on walls decreased in March through early April and also in August in ambient channels; in June and August in +2 C channels; in both +4 and +6 C channels in March and April, as well as in June through August. Rock area density declines differed from those on walls only in the two coolest treatments; in ambient channels, the spring decrease extended into early May, while in +2 C channels there was a definite decrease in April. Pool sediments had declines in April and early May in ambient and +6 C channels, but no spring declines at the two intermediate temperature treatments. The late summer drops occurred in July and August in the two coolest treatments and in June through August in the two warmest temperatures.

Most changes in density were paralleled by changes in biomass (Figs. 22 through 24). Sampling intervals which did not show similar trends for these two parameters revealed either an increased population size at the expense of biomass or increased biomass with decline in population size. These trends revealed when and where recruitment occurred, corroborating the evidence of density alone.

In ambient pool areas, the number of small *Caenis* nymphs increased in May and early June, during and following spring density decreases; in +2 C and +4 C channels, the same relationship was seen earlier, during April and in early May. In +4 C channels, recruitment occurred in June and July. *Caenis* in +6 C channels did not demonstrate trends such as these.

In rock areas, recruitment occurred in ambient channels in May; in +2 C channels in April and early May, and also in June and July. Neither +4 C nor +6 C channels provided clear evidence of any early *Caenis* nymphal instars.

TABLE 24. ANOVA OF TREATMENT EFFECTS ON DRY WEIGHT (mg m^{-2}) OF *CAENIS* SP.†

	A	+2 C	+4 C	+6 C	DF	Error S.S.	Error M.S.	Treatment Effects§
Apr*	61	49	238	148				
May	23	13	23	55	8	1.3308	0.1663	+6 > +2
Jun	18	228	366	465	8	0.3339	0.0417	+2 = +4 = +6 > A
Jul	423	87	80	64	8	1.5067	0.1883	
Aug	61	38	13	1	8	4.537	0.5671	A > +6

† Performed on log-transformed means (three replicates) using least significant differences (Sokal and Rohlf, 1969).

§ $P \leq 0.05$.

* Too few samples for analysis.

TABLE 25. ANOVA OF TREATMENT EFFECTS ON MEAN DENSITY (no m^{-2}) OF *CAENIS* SP.†

	A	+2 C	+4 C	+6 C	DF	Error S.S.	Error M.S.	Treatment Effects§
Apr*	133	98	269	317				
May	41	117	370	371	8	0.4388	0.0548	+4 = +6 > A = +2
Jun	199	946	1207	1766	8	0.3617	0.0452	+6 > A
Jul	1943	643	546	462	8	1.0879	0.1359	
Aug	632	383	187	150	8	0.5172	0.0646	A > +4 = +6

† Performed on log-transformed means (three replicates) using least significant differences (Sokal and Rohlf, 1969).

§ $P \leq 0.05$.

* Too few samples for analysis.

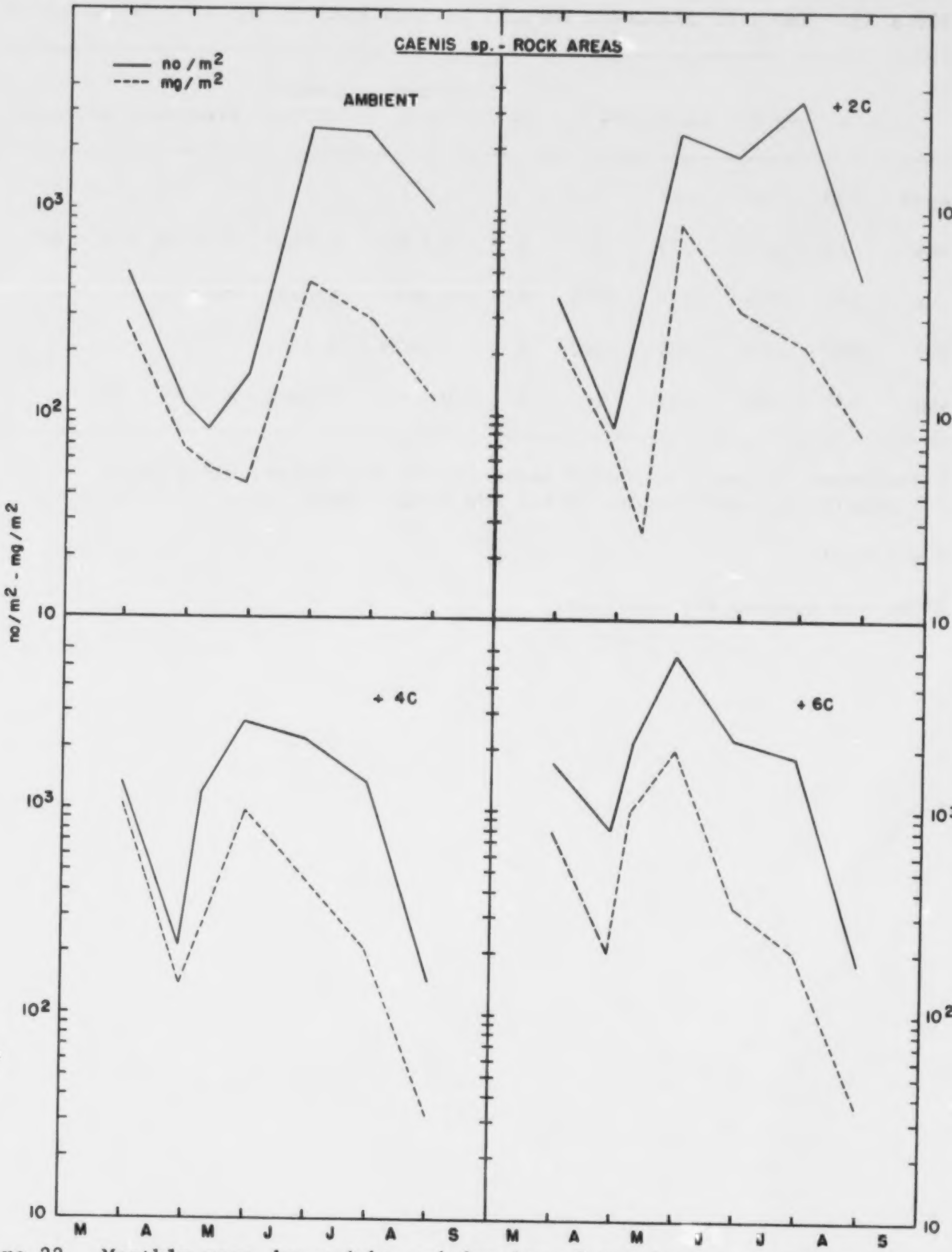

Figure 22. Monthly mean dry weight and density of *Caenis* sp. on rock areas of four temperature treatments (three channels per treatment): A (ambient temperature of Wheeler Reservoir, Tennessee River), and +2°, +4°, and +6° C above ambient.

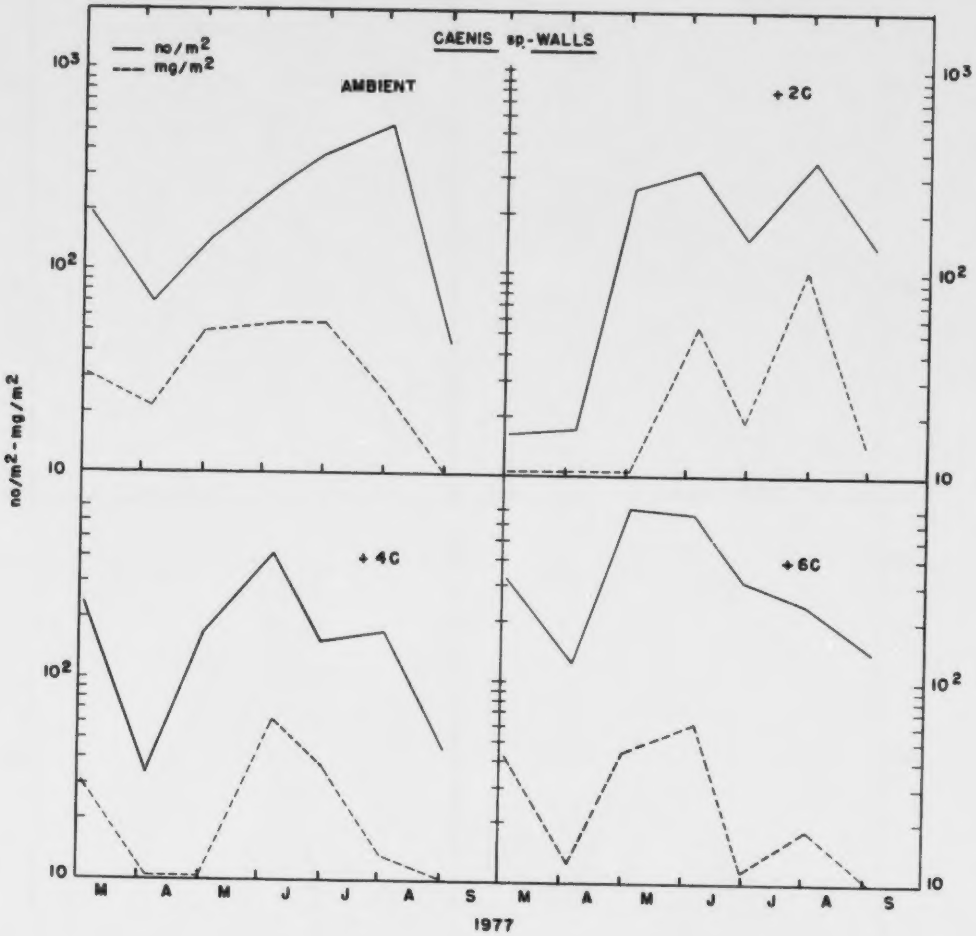

Figure 23. Monthly mean dry weight and density of *Caenis* sp. on wall areas of four temperature treatments (three channels per treatment): A (ambient temperature of Wheeler Reservoir, Tennessee River), and +2°, +4°, and +6° C above ambient.

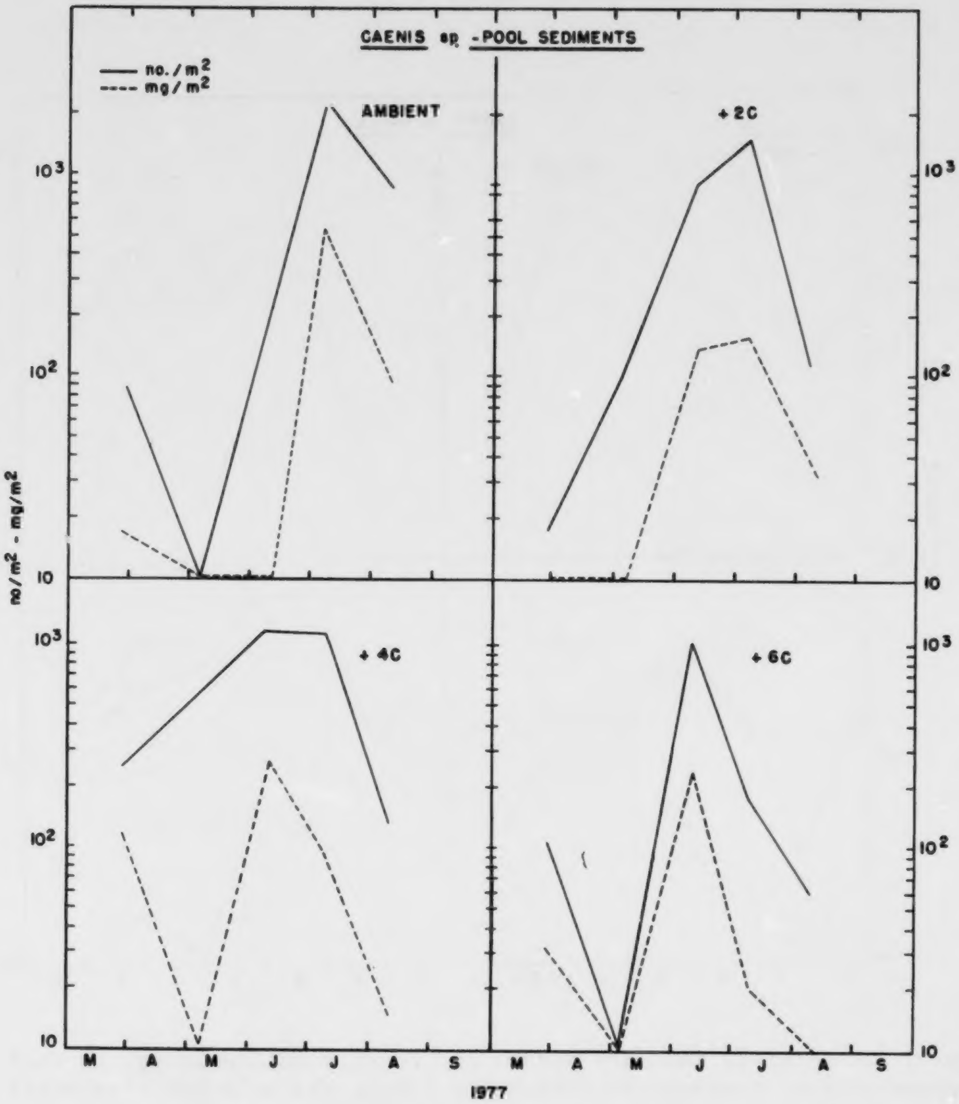

Figure 24. Monthly mean dry weight and density of *Caenis* sp. in pool areas of four temperature treatments (three channels per treatment): A (ambient temperature of Wheeler Reservoir, Tennessee River), and +2°, +4°, and +6° C above ambient.

Wall surfaces recruited young *Caenis* nymphs in May, June, and July in ambient channels, and in July in +4 C channels. An increase in biomass at the expense of population numbers occurred in wall surfaces oftener than in the other habitats, especially in March and August in ambient channels; in August in +4 C channels, and in July and May in +6 C channels.

Chironomidae

At least three subfamilies in the family Chironomidae were represented in the experimental channels in 1977. No attempt was made to further classify them.

As for *Caenis* sp., Chironomidae dry weight peaks occurred in the three warmest treatments in early June (600 to 950 mg m^{-2}). In the +2 C channels, the peak extended into July (Table 26, Fig. 25). The ambient peak did not appear until the final sampling date in August (1087 mg m^{-2}) following a temperature decrease from 30° to 28.5° C during the preceding month. At the time of peak biomass in the warmest channels, these channels had greater dry weight ($P \leq 0.05$) than did ambient channels. In August, biomass in the ambient channels was greater than that in +2 C and +4 C channels ($P \leq 0.05$) but not significantly different from that in +6 C channels.

Chironomidae density curves were similar to the dry weight curves with two exceptions: The +2 C curve did not reach a peak until early July at 6189 m^{-2}, and the ambient curve did not decline after early April (Table 27, Fig. 26). The greatest densities in +4 and +6 C treatments were 5682 and 4265 m^{-2}, respectively, in June. The greatest chironomid density in ambient channels, which appeared in June, was 11,113 m^{-2}, a significantly greater density ($P \leq 0.05$) than in any other channel.

Chironomid densities were generally greatest in pool areas, ranging as high as 9353 m^{-2} in +4 C channels in June. The +6 C channel peak in June (6079 m^{-2}) was not very different from the peak attained in rock areas (5821 m^{-2}) at the same time in the same channels. Densities on wall areas were the lowest, not exceeding 536 m^{-2} in any treatment (Fig. 27, Table A-4). In all treatments on final sampling dates, pool sediments had the highest densities and walls the lowest, with rock areas having intermediate densities.

Declines in density, indicating probable emergence, were most clearly related to temperature treatment in pool areas. Emergence from +4 and +6 C treatments occurred in June, from +2 C channels in May, and from the ambient regimen in August following a density peak. Density declines in wall and rock area curves were evident in all treatments during June.

Hirudinea

Three leech species were dominant during the experimental period; *Erpobdella punctata*, *Helobdella* sp., and *Placobdella montifera*. These species were combined for biomass estimates. Because hirudinids had been shown to be important fish food organisms (unpublished data), they were analyzed statistically for effects of treatment; however, because so few

TABLE 26. ANOVA OF TREATMENT EFFECTS ON DRY WEIGHT (mg m^{-2}) OF CHIRONOMIDAE.†

	A	+2 C	+4 C	+6 C	DF	Error S.S.	Error M.S.	Treatment Effects§
Apr*	531	31	79	2				
May	218	108	494	28	8	0.4392	0.0549	A = +4 > +6, +2 > +6
Jun	129	934	621	854	8	0.5878	0.0734	+2 = +4 = +6 > A
Jul	177	996	84	180	8	1.3056	0.1632	+2 > A = +6 > +4
Aug	1087	174	68	241	8	1.8949	0.2368	A > +2 = +4

† Performed on log-transformed means (three replicates) using least significant differences (Sokal and Rohlf, 1969).

§ $P \leq 0.05$.

* Too few samples for analysis.

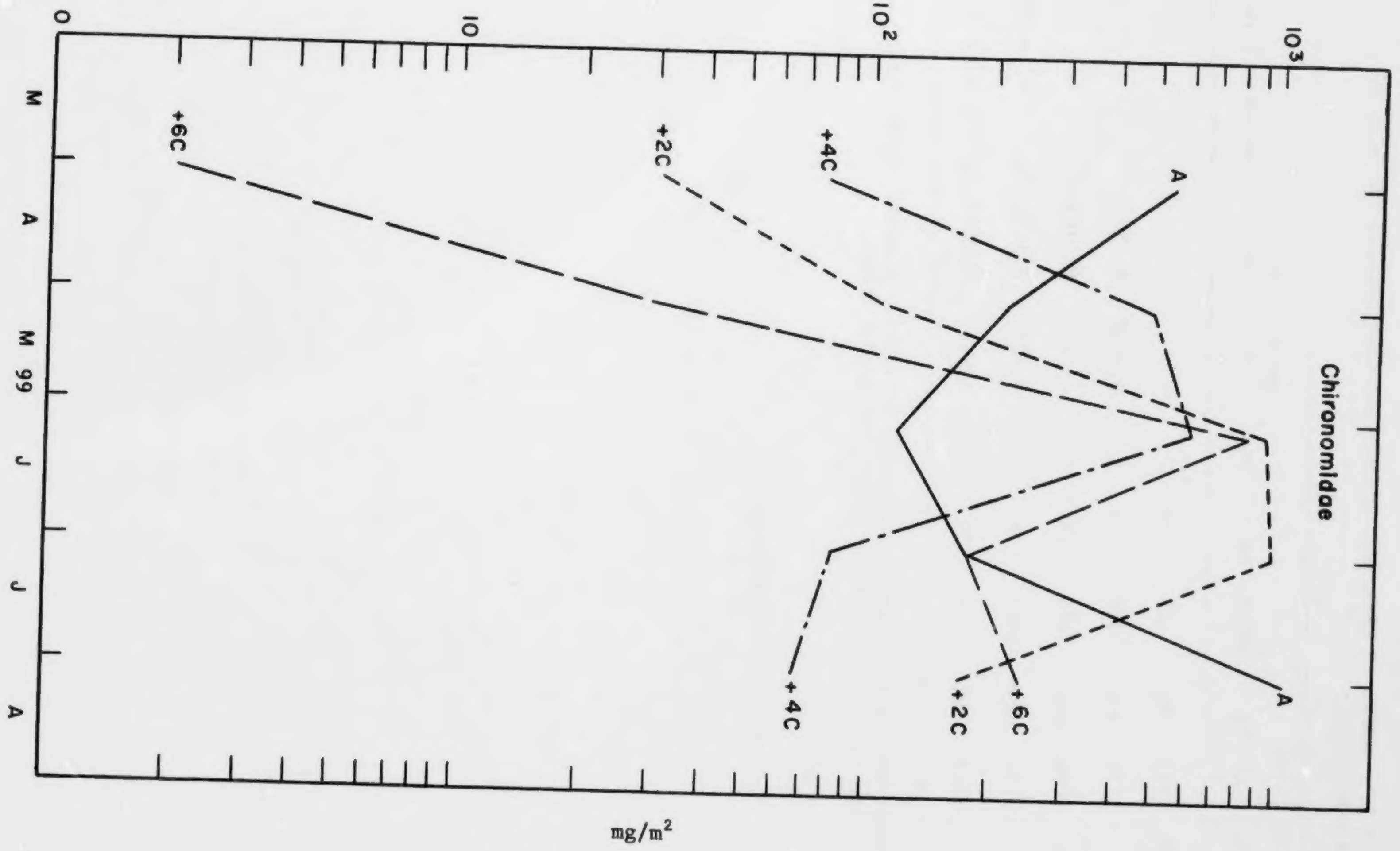

Figure 25. Monthly mean dry weight of Chironomidae in four temperature treatments (three channels per treatment): A (ambient temperature of Wheeler Reservoir, Tennessee River), and +2°, +4°, and +6° C above ambient.

TABLE 27. ANOVA OF TREATMENT EFFECTS ON MEAN DENSITY (no m^{-2}) OF CHIRONOMIDAE.†

	A	+2 C	+4 C	+6 C	DF	Error S.S.	Error M.S.	Treatment Effects§
Apr*	1213	160	18	11				
May	1571	948	1840	741	8	0.4010	0.0501	
Jun	1096	3539	5682	4265	8	1.1067	0.1383	
Jul	1750	6189	1068	1264	8	0.8282	0.1035	+2 > = +4 = +6
Aug	11113	1191	318	1347	8	0.9718	0.1214	A > +2 = +4 = +6.

† Performed on log-transformed means (three replicates) using least significant differences (Sokal and Rohlf, 1969).

§ $P \leq 0.05$.

* Too few samples for analysis.

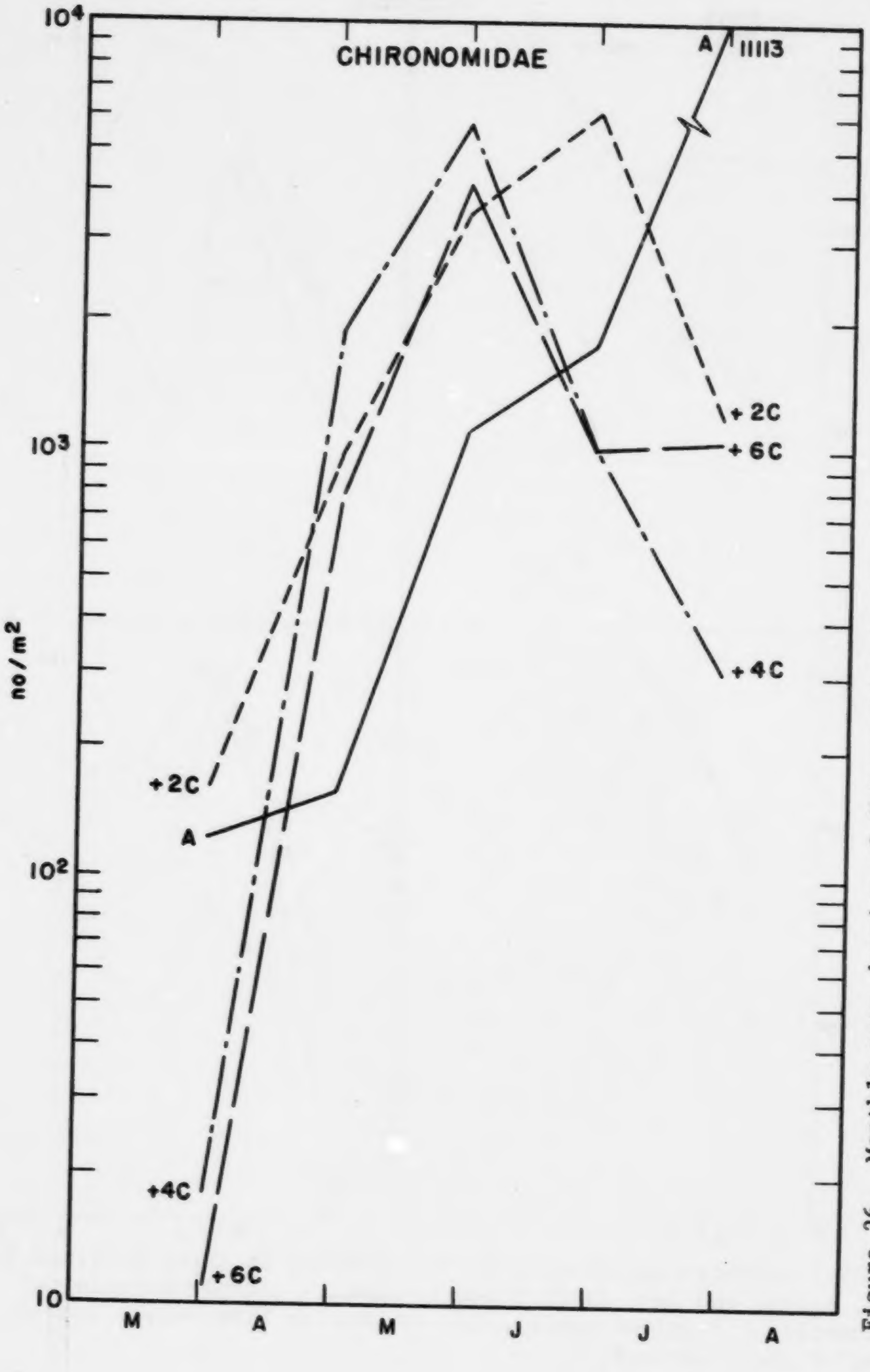

Figure 26. Monthly mean density of Chironomidae in four temperature treatments (three channels per treatment): A (ambient temperature of Wheeler Reservoir, Tennessee River), and +2°, +4°, and +6° C above ambient.

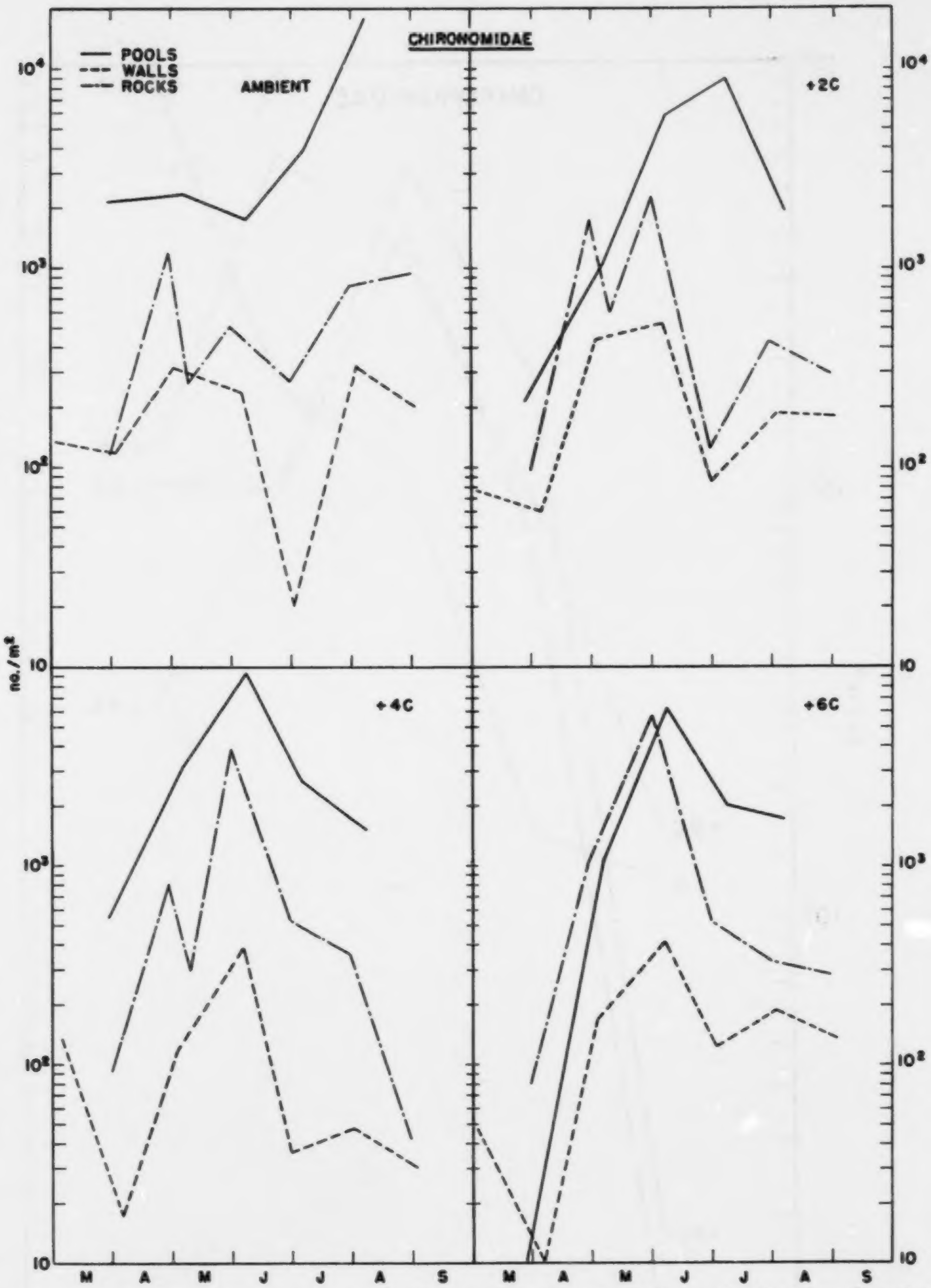

Figure 27. Monthly mean density of Chironomidae in three habitats (rocks, walls, pools) and four temperature treatments (three channels per treatment): A (ambient temperature of Wheeler Reservoir), and +2°, +4°, and +6° C above ambient.

treatment effects were seen, their population data are not presented graphically. In early May, greatest biomass occurred in all treatments, followed by decline in all but the +2 C regimen (Table 28). The +4 C channels had the largest biomass in May (ca. 41. gm m^{-2}). By the end of the study, no treatment dry weight exceeded 36 mg m^{-2}. The only obvious treatment effect occurred in July, when ambient and +2 C hirudinid dry weights were greater than those of +4 and +6 C channels.

Other Macroinvertebrates

Other macroinvertebrates occasionally abundant, or adding measurably to community biomass, were Oligochaeta, Libellulidae, and Trichoptera. Oligochaete and Trichoptera densities and dry weights appear in Table A-4.

All Anisoptera nymphs sampled were respresentatives of the family Libellulidae. Their densities were never great; however, because of their large size, their contribution to total dry weight was measurable. Greatest libellulid dry weight was estimated in +6 C channels (878 mg m^{-2}) in early April (Table 29). All other channels had their greatest biomass in early May, followed by a decline to 12 mg m^{-2} or less in all treatments. A predictive treatment effect was noted in May, when +6 C libellulid dry weight was significantly greater than that in ambient and +2 C regimens ($P \leq 0.05$).

Percent Abundance and Dry Weight Biomass

Percent abundance and percent dry weight, excluding Mollusca, were determined separately for each habitat, in order to discern community differences. In general, four organisms were consistently dominant in one or more habitats; *Physa heterostropha*, Amphipoda, *Caenis* sp., and Chironomidae. In pool areas, oligochaetes were often among the dominant taxa; in rock areas and on walls, *Pyrgulopsis letsoni* was occasionally an important component.

Along walls, *P. heterostropha* percent abundance ranged from 8% in +4 C channels in March to 91% in ambient channels in early April (Table A-8). Except for one measurement in July when they comprised 46% in the +6 C channels, after May they did not again comprise more than 50% of total numbers. *P. letsoni* were never found in ambient channels, but did form 75% of the community in the +4 C channels in August, following a gradual increase in dominance. In May, *Caenis* comprised up to 50% of +6 C channels' community density, and usually formed a larger part of the warmest channels. Chironomidae populations ranged from 0 to 39% of total numbers. No trends were noted, either seasonally nor by treatment. Amphipoda were relatively abundant (40 to 50%) in +2 and +4 C channels on March 2, and in +2 C channels on July 1.

The greatest contribution of *P. heterostropha* to rock-area community numbers (76%) was noted in + 2 C channels on March 30 (Table A-8). On 27 April and 11 May, ambient channels had *Physa* populations comprising 54% and 41%, respectively, of total numbers. Toward the end of the study, *Physa* were more numerous in warmest channels than in the three cooler treatments.

TABLE 28. ANOVA OF TREATMENT EFFECTS ON DRY WEIGHT (mg m^{-2}) OF HIRUDINEA.†

	A	+2 C	+4 C	+6 C	DF	Error S.S.	Error M.S.	Treatment Effects§
Apr*	955	284	476	772				
May	1628	527	4085	2437	8	11.2487	1.4060	
Jun	278	538	31	8	8	5.7430	0.7178	
Jul	270	54	22	15	8	4.3805	0.5475	A = +2 > +4 = +6
Aug	36	3	13	6	8	4.0975	0.5121	

† Performed on log-transformed means (three replicates) using least significant differences (Sokal and Rohlf, 1969).

§ $P \leq 0.05$.

* Too few samples for analysis.

TABLE 29. ANOVA OF TREATMENT EFFECTS ON DRY WIEGHT (mg m^{-2}) OF LIBELLULIDAE.†

	A	+2 C	+4 C	+6 C	DF	Error S.S.	Error M.S.	Treatment Effects§
Apr*	0	0	33	878				
May	33	53	326	609	8	5.0134	0.6266	+6 > A = +2
Jun	0	0	0	6	8	0.9666	0.1208	
Jul	0	0	0	12	8	1.6147	0.2018	
Aug	0	11	12	1	8	1.2654	0.1581	+2 = +4 > A = +6

† Performed on log-transformed means (three replicates) using least significant differences (Sokal and Rohlf, 1969).

§ $P \leq 0.05$.

* Too few samples for analysis.

P. letsoni achieved percent abundance over 15% only in +4 C channels on August 31, when it contributed 67% to total numbers. *Caenis* composed up to 61% of the community, generally being most numerous in all treatments in June and July. Neither Chironomidae nor Amphipoda percent abundances on rock areas were affected by treatment.

Community structure in pool sediments was quite different from that in either rock or wall areas (Table A-8). Chironomids and oligochaetes were almost always the two most abundant organisms. Chironomids comprised up to 74% numerically in ambient channels in March and only once, on the same date in +6 C channels, were nonexistent. Oligochaetes tended to be more numerous in all treatments at the beginning of the sampling period than at the end. In March, they were 54% of the community in +2 C channels, and 55% in +6 C channels in both March and May. While *P. heterostropha* was most numerous in June and July, it never comprised more than 32% of any treatment. *Caenis* was even less numerous, comprising only 15% in +4 C channels in July. Although Amphipoda numbered 18% and 17% in ambient channels in June and July, they were usually nonexistent in all treatments.

On wall surfaces, Libellulidae biomass, even when low in numbers, was often important in the community, attaining 83% in +6 C channels in September (Table A-4) when in all treatments they were at their highest percent biomass. *Caenis* dry biomass ranged from 3% in +2 C channels in March to 71% in +2 C channels in August. Greatest contribution of *Caenis* in ambient channels occurred in April (60%), in +4 C channels in July (61%), and in +6 C channels in June (51%). Chironomidae biomass comprised 70% of the total in +2 C channels in April when no libellulid weight was present. In ambient channels in March, it accounted for 50% of total weight but in most cases contributed no more than 20%. Amphipoda occasionally comprised more than 50% of total weight especially in the two coolest treatments.

In rock areas, both libellulids and Hirudinea were important components of the community in terms of weight (Table A-9). Libellulids were dominant, particularly in warmest channels in April and May and were also important toward the end of the sampling period. Hirudinea biomass was 75% of the total on May 31 in ambient channels, 50% in +6 C channels in March, and 30% or less in most other cases. *Caenis* percent dry weight was greatest in May when the three warmest treatments had 53, 54, and 62% *Caenis* by weight. The highest ambient value was on the first sampling date at 49%. Lowest values occurred, generally in April and early May in all treatments. Chironomidae were less important than *Caenis* in terms of dry weight. Percent contribution did not range above the 36% value noted in +6 C channels at the end of August. Amphipoda composed as much as 44% of dry biomass in +2 C channels in April but on most dates contributed 20% or less in all treatments.

In pool sediments, total dry weight was dominated by Chironomidae, Hirudinea, and Oligochaeta; Hirudinea were dominant in all treatments (up to 92%) early in the sampling period, Chironomidae from mid-June through August, and Oligochaeta in July and August. *Caenis* were relatively more important toward the end of the sampling period than toward the beginning. Amphipod weight was significant enough to be measured only in June and July and only in the two coolest treatments. Libellulidae biomass was noted only in +6 C channels in March when it contributed 97% to total weight.

Diversity

Species diversity (Shannon-Weaver H^1) in the experimental channels ranged from 0.45 on walls in ambient channels in April to 2.23 in +4 C channels in rock areas in June (Table 30). Most values ranged between 1.40 and 1.90. No trend was seen relating diversity to temperature treatment. Annual means indicated greatest diversity in +4 C channels (1.62). Mean diversity across treatments was greater toward the middle of the sampling period. Statistically, the only significant difference seen ($P \leq 0.01$) was in the pool areas, where +4 C channels had higher diversity than +6 C channels (Table 32).

Diversity of biomass was also difficult to relate to temperature treatment or to season (Table 31). Biomass values ranged from 0.15 in March +6 C pool areas to 1.81 in July ambient pool sediments. Mean biomass diversity, however, was highest in ambient channels in all habitats. Statistically, differences in biomass diversity were seen in pool ($P \leq 0.01$) and rock areas ($P < 0.05$) where ambient channel diversities were greater than +6 C channel diversities (Table 32). Also in rock areas, biomass diversity was greater in +2 C channels than in either +4 or +6 C channels ($P < 0.05$).

Bluegill Stomach Contents

In a sample of bluegill (15 per treatment) ranging from 136 to 146 mm TL, collected 8 September, Chironomidae were dominant in stomach contents (Table 33). In the ambient and +2 C channels, chironomid larvae were the prevalent form; in +4 C channels, both larvae and pupae were present and in fish from +6 C channels, pupae were prevalent. *P. heterostropha* were seen primarily in stomachs from +6 C channel fish; 60% of these had ingested *Physa*. Thirty percent of +2 C channel bluegill and 13% of ambient and +4 C fish had fed on *Physa*. All other organisms were present in 30% or fewer stomachs. Hydroptilidae larvae were seen only in fish from the two coolest channels; Amphipoda were seen only in fish from ambient channels. *Caenis* were found in four ambient treatment bluegill and one +6 C bluegill. Most stomachs from all treatments contained at least some algae along with macroinvertebrates.

DISCUSSION

Of the groups of organisms observed during this experiment, some were greatly affected by temperature treatments, some moderately affected, and some not at all affected.

Total Macroinvertebrates

Although the evaluation of the total macroinvertebrates included more than 75 species, there were treatment effects in terms of peak abundance. Elevated temperature regimens, particularly +4 and +6 C, advanced the time

TABLE 30. SPECIES DIVERSITY (SHANNON-WEAVER H^1) IN THREE HABITATS OF FOUR TEMPERATURE TREATMENTS ON ALL SAMPLING DATES.

	A	+2 C	+4 C	+6 C	$\bar{X}$
Walls					
March 2	1.64	1.31	1.74	1.54	1.55
April 5	0.45	0.52	0.86	0.94	0.69
May 2	0.87	1.38	1.31	1.69	1.31
June 6	1.57	1.66	2.10	1.76	1.77
July 1	1.43	1.87	1.76	1.77	1.70
August 2	1.66	1.81	1.18	1.85	1.62
September 2	1.86	1.84	1.02	1.65	1.59
$\bar{X}$	1.35	1.48	1.43	1.60	
Pool Sediments					
March 24	1.04	1.48	1.69	1.27	1.37
May 6	1.85	1.84	1.63	1.18	1.62
June 10	1.59	1.69	1.53	1.06	1.46
July 7	2.10	1.38	1.58	1.44	1.62
August 8	1.26	1.42	1.81	1.49	1.49
$\bar{X}$	1.57	1.56	1.65	1.29	
Rock Areas					
March 30	1.54	0.94	1.62	1.42	1.38
April 27	1.51	1.95	2.03	2.09	1.89
May 31	1.70	1.61	1.67	1.08	1.51
June 28	1.96	1.88	2.23	1.62	1.92
July 28	1.93	1.51	1.86	1.42	1.68
August 31	1.84	1.66	1.36	1.56	1.60
$\bar{X}$	1.75	1.59	1.79	1.53	

TABLE 31. BIOMASS DIVERSITY (SHANNON-WEAVER H^1) IN THREE HABITATS OF FOUR TEMPERATURE TREATMENTS ON ALL SAMPLING DATES.*

	A	+2 C	+4 C	+6 C	$\bar{X}$
Walls					
March 2	1.13	1.04	1.39	1.42	1.25
April 5	0.80	0.80	1.07	1.15	0.96
May 2	1.48	1.29	1.11	1.17	1.26
June 6	1.17	1.05	1.21	1.36	1.20
July 1	1.12	1.21	1.17	1.32	1.21
August 2	1.64	1.01	1.31	1.29	1.31
September 2	1.25	1.13	0.74	0.59	0.93
$\bar{X}$	1.23	1.08	1.14	1.19	
Pool Sediments					
March 24	0.93	0.31	0.84	0.15	0.56
May 6	0.40	0.47	0.38		0.73
June 10	1.12	1.09	0.59	0.61	0.85
July 7	1.81	1.24	1.13	1.31	1.37
August 8	1.27	0.92	0.91	0.47	0.89
$\bar{X}$	1.12	0.81	0.77	0.64	
Rock Areas					
March 30	1.22	1.48	1.48	1.31	1.37
April 27	1.32	1.51	1.35	0.71	1.22
May 31	1.61	1.22	1.21	0.83	1.22
June 28	1.54	1.29	1.04	1.18	1.26
July 28	1.71	1.42	1.34	1.00	1.37
August 31	1.67	1.56	1.38	1.58	1.55
$\bar{X}$	1.51	1.41	1.30	1.10	

* Mean dry weights m^{-2} of dominant populations related to each other.

TABLE 32. RESULTS OF STUDENT'S *t* TEST ON MACROINVERTEBRATE DIVERSITY INDICES.†

	Numbers				Walls	Biomass			
	A	+2 C	+4 C	+6 C		A	+2 C	+4 C	+6 C
A	-	N.S.	N.S.	N.S.	A	-	N.S.	N.S.	N.S.
+2 C		-	N.S.	N.S.	+2 C		-	N.S.	N.S.
+4 C			-	N.S.	+4 C			-	N.S.
+6 C				-	+6 C				-

					Pool Sediments				
	A	+2 C	+4 C	+6 C		A	+2 C	+4 C	+6 C
A	-	N.S.	N.S.	N.S.	A	-	N.S.	N.S.	A 0.01
+2 C		-	N.S.	N.S.	+2 C		-	N.S.	N.S.
+4 C			-	+4 0.01	+4 C			-	N.S.
+6 C				-	+6 C				-

					Rock Areas				
	A	+2 C	+4 C	+6 C		A	+2 C	+4 C	+6 C
A	-	N.S.	N.S.	N.S.	A	-	N.S.	N.S.	A 0.05
+2 C		-	N.S.	N.S.	+2 C		-	+2 0.05	+2 0.05
+4 C			-	N.S.	+4 C			-	N.S.
+6 C				-	+6 C				-

† $P <$ values indicated.

A, +2, +4 - indicates treatment with greater diversity.

N.S. - non significant.

TABLE 33. STOMACH CONTENTS OF BLUEGILL RECOVERED 1 SEPTEMBER FROM FOUR TEMPERATURE TREATMENTS.

	Chironomidae pupae	Chironomidae larvae	*Caenis*	Amphipoda	Hirudinea	Hydroptilidae	*Physa*	Fish	Miscellaneous
Ambient									
1		4							
2		11							24 bryozoan statoblasts
3		2		2					
4			3				3	1	
5		1		1					11 Copepoda
6		23			1	5			
7	2	2							
8	3	5							1 *Hexagenia*, 2 *Cyrnellus*
9		60							4 Ceratopogonidae
10		2	2				3		
11	1	1							1 Ceratopogonidae
12		4	1			2			1 Ceratopogonidae
13		2				4			
14		10	1						
15	1	1							
+2 C									
1	1	45							
2		1			2	3	5		
3		1							
4									1 *Pyrgulopsis*
5		58					3		2 Ceratopogonidae ostracods
6		1							
7	1	24							
8	2	13			2		1		
9		11							1 Ceratopogonidae
10	1	42					1		
11	1	10				1	5		1 Ceratopogonidae
12		3							
13	2	40							1 Ceratopogonidae
14		1					1		
15	4	60							

(continued)

TABLE 33 (continued).

	Chironomidae pupae	Chironomidae larvae	*Caenis*	Amphipoda	Hirudinea	Hydroptilidae	*Physa*	Fish	Miscellaneous
+4 C									
1	4								3 adult Chironomidae, 1 coroxid
2	2	6							
3	2						6		1 Ceratopogonidae
4		78							
5	2	1							1 Ceratopogonidae
6	1								
7	9	13						1	1 adult Chironomidae
8									
9							6		
10									
11									
12	24							1	2 adult Chironomidae
13	4								
14		1							1 hemipteran
+6 C									
1	39						1		
2	17						3		2 *Pyrgulopsis*
3	10								
4	8						1		1 *Pyrgulopsis*
5									
6							5		
7									
8	10							1	
9	18						4		2 Ceratopogonidae, 2 *Pyrgulopsis*
10	9						1		
11	15				1		2		
12	17	2							
13	7						4		1 nematode
14		5					8	1	1 Hydrophilidae
15	10		1				3	1	

of greatest density at least one month. This phenomenon was true also for total biomass, exclusive of Mollusca. Also, in May, greatest dry weights in the two warmest treatments (3-5 gm m^{-2}) surpassed those in the two coolest treatments (ca. 2 gm m^{-2}).

The relative decimation of macroinvertebrate biomass in +4 and +6 C channels and of macroinvertebrate densities in +2, +4, and +6 C channels during the last month, as compared with those in cooler channels may be attributed directly to temperature increase, indirectly to excessive predation, or a combination of both. The highest growth rate of bluegill in all treatments generally coincided with the density-biomass peaks of invertebrates. However, the decline of macroinvertebrate populations in the heated channels was not reflected in the yield (biomass) of bluegill recovered 9 September, which was not significantly different between temperature treatments. Future studies should be continued into the winter to determine if the macroinvertebrate populations would recover their initial levels. Dry weight of the macroinvertebrates in ambient channels was about the same at the end of the experiment as it was at the beginning, indicating effective efficient turnover while providing a food base for bluegill.

Gastropoda

Gastropods are almost ubiquitous components of freshwater lotic and lentic ecosystems. Those occurring in the experimental channels are common in many areas; *Lymnaea* spp. are common in almost every area in the United States, as are *Helisoma* spp. Pleuroceridae are found mainly east of the Mississippi River and are common in Alabama, and *Physa* spp. inhabit all types of waters, but are most often found in waters of northern states. *Pyrgulopsis* spp. have several representatives in the upper Mississippi Valley, Great Lakes region, Alabama, and Nevada (Pennak, 1953).

Experiments to determine effects of temperature on gastropods have typically been carried out in small laboratory systems utilizing one species at a time at constant temperatures. Several of these studies demonstrated that whereas temperatures near 30° C were optimal for maximum growth, these temperatures also inhibited reproduction (e.g., Michelson, 1961; and Berrie, 1969). Van der Shalie and Berry (1973) showed in laboratory studies that lymnaeids grew best at 18° C with viability reduced at 22° C and above, that planorbids grew best at 25° C with reproduction inhibited at 30° C, and that physids tolerated the widest temperature range, sometimes living at 30° C and above. None of the snails in these studies reproduced in the laboratory at above 30° C. McDonald (1975) showed 30° C to be the incipient lethal level for *Lymnaea stagnalis*. This was the highest temperature to which this species could be exposed while maintaining behavior patterns observed at lower temperatures. In thermal gradients in the laboratory, Chernin (1967) found that *Lymnaea palustris* accumulated in cool regions and avoided the area above 32° C. Bovjerg (1975) noted that *Lymnaea stagnalis* in an experimental gradient ranging from 25° to 35° C avoided the 35° C area. Dewitt (1954) found oviposition in *Physa gyrina* to be induced by a rise in temperature and that the time needed for development prior to hatching was directly proportional (within limits) to temperature. Imhof

(1973) showed growth regulation in lymnaeids to be related to laboratory temperature within the range prevailing during the warm season in the snails' habitat. Above specific threshold values, no correlation existed between temperature level and intensity of spawning. Imhof also showed that lengthening daylight stimulated spawning.

Mattice (1975) subjected *Lymnaea obrussa* Say to both constant and varying temperatures and found varying temperatures to be more conducive to growth; snails held at 30° C died at the end of the third week of the experiment without producing eggs.

Two recent studies on *Physa* were conducted in natural systems receiving heated effluents. Sankurathri and Holmes (1976) studied *Physa gyrina* in two areas of Lake Wabamun in Alberta, one area with heated effluent, ranging to 32° C, about 8° C above the other unheated area. In the unheated area was found a preponderance of miniature snails, and a preponderance of large mature snails occurred in the heated area. There was little seasonal pattern to the appearance of egg masses, immature and mature snails, in the heated areas; all sizes were present throughout the year. There was egg development up to 32° C.

McMahon (1975) refuted evidence of laboratory experiments that pulmonate snails will not reproduce at temperatures above 30° C (Van der Schalie and Berry, 1973). He studied the life cycle of *Physa virgata* in an impoundment in Texas (Lake Arlington) in which one area received heated effluent while another did not. He found that in the heated effluent, this species completed three generations per year and cited this as the first case in which this phenomenon had been shown in the Physidae. *P. virgata* spawned at temperatures up to 39.5° C in this heated area. He observed a more rapid rate of growth of the second generation in the heated effluent and inferred that in 17 years of temperature elevation, separate physiological races had developed in the heated and unheated areas of the impoundment.

Physa heterostropha in the experimental channels were not greatly affected by the temperature increments to which they were exposed. Eggs were observed in this study in late August in all treatments. Those in +6 C channels were laid in temperatures of 33° to 34.5° C, corroborating Sankurathri and Holmes' (1976) and McMahon's (1975) findings. Whether these eggs were viable was not determined due to termination of the experiment. The size distribution in all treatments (although not examined statistically) was similar to that in the heated areas of Lake Wabamun (Sankurathri and Holmes, 1976) where all sizes were present most of the time. However, the predominance of large snails in warmer water and small snails in cooler water was not seen in the channels.

Physa densities in ambient channels at the end of the study were at least three times greater than those in any other treatment. Although this difference was not significant, it indicates that of the four treatments, ambient was most favorable for growth, assuming the absence of differential predation by fish or large invertebrates. In an earlier study in which two channels with fish were compared with two without, there was no significant difference in gastropod densities between treatments (unpublished data).

However, the data from examination of bluegill stomachs at the termination of the present study implied greatest predation on *P. heterostropha* in +6 C channels and least in ambient and +4 C channels. Not clearly demonstrated, therefore, was that temperature alone effected treatment variance.

In all but the warmest channels, *Physa* populations along walls and on rock areas began to decline in April and May, while those in pool areas increased. There was either a migration at this time and/or a dying-off with young snails. One common pulmonate life cycle has two generations per year (McMahon, 1975), a spring generation which hatches from eggs laid by overwintering snails and which matures and breeds in late summer or fall, giving rise to a second generation. Most snails die after breeding but usually some of those breeding in the fall survive through the following winter and reproduce a second time in the spring. Eggs were observed in all treatments in late March and early April, in June and July, and in early September. Masses of large *Physa* were seen floating at the surface of the water, feet up, toward the end of March and also in mid-June. Possibly these were snails which had reproduced and were dying. McCraw (1970) who studied *Lymnaea palustris* (Müller) also remarked that most of a generation may die during the month after a period of active egg-laying. If true, *Physa* had at least two generations in the channels, regardless of temperature treatment. Further studies concentrating on individual species will be necessary to better define the life cycle. Although final densities varied between treatments, life cycles apparently did not. Pool area populations in the warmest channels did not recover as much in June as they did in other treatments, but the small recovery was synchronized with recoveries in other treatments, indicating the same life cycle.

The preponderance of *Pyrgulopsis letsoni* in +4 C channels existed early in the study and was evidently not initiated by temperature treatment. The population which colonized these channels was able to persist undecimated for the duration of the experiment. Because significant populations were never present in other treatments, it is impossible to say that temperature was a factor influencing the persistence of this snail in +4 C channels. Predation by fish was probably not a factor, since bluegill had not shown significant feeding on *Pyrgulopsis* (unpublished data and Table 33).

The laboratory studies cited showed lymnaeids to be somewhat less tolerant of elevated temperature than physids. *Lymnaea* densities in the channels decreased to zero toward the end of the sampling period and did so earlier in heated than in ambient channels, supporting these studies.

Amphipoda

The two genera of amphipods inhabiting the experimental channels, *Hyalella* and *Crangonyx*, are widely distributed and common in shallow clean waters of all types (Pennak, 1953). These genera differ in food habits, geographic distribution, and life cycles. *Hyalella* feeds largely on epibenthic algae and the bacterial community while *Crangonyx* is often carnivorous (Mathias, 1971). *Hyalella* occurs on both the North and South American continents while *Crangonyx* is restricted to the North American continent. *Crangonyx* females die after producing only one brood per year;

Hyalella females average 15 broods in 152 days (Pennak, 1953).

Few studies have been designed specifically to elucidate the effects of elevated water temperatures on amphipods. Observations of temperature effects have occasionally arisen from population studies in natural systems. Mathias (1971) studied *Hyalella azteca* and *Crangonyx richmondensis occidentalis* in Marion Lake, British Columbia. He found amphipods of the *Crangonyx* group to be more tolerant of cold water than were *Hyalella* and that the former group often bred in winter and spring when water temperatures were as low as 5-15° C. Mathias also demonstrated that *Hyalella*'s brood period, or the mean period between deposit of eggs in the female brood pouch and release of free-swimming young, ranged from 33 to 7 days as temperature was increased from 10° to 25° C. Strong (1972) reported that *H. azteca* reproduced year-round in a hot spring at temperatures between 12° and 40° C.

Temperature effects on *Crangonyx* and *Hyalella* life cycles differed. *Crangonyx* were usually less numerous and less heat-tolerant than *Hyalella*. The trophic status of *Crangonyx* as carnivores might account for their lesser abundance, and their cold-tolerance (Mathias, 1971) might imply a lack of heat-tolerance in this experimental system. The first gravid female *Crangonyx* were found in ambient and +2 C channels in March. They were not found in warmer channels until April and were again seen in ambient channels in May, possibly indicating two brood periods, which could be verified only through further study of *Crangonyx*.

Hyalella populations first had gravid females in early April in +6 C channels, in late April in +2 C and +4 C channels, and in early May in ambient channels. These data indicated later breeding in *Hyalella* than in *Crangonyx* and a temperature effect as well. In early June, gravid *Hyalella* females were still seen in all treatments; in late June, they were found only in the two coolest treatments, and by early July only in ambient channels. Apparently, when temperatures rose above about 30° C, *Hyalella* were no longer able to reproduce, unlike *H. azteca* of hot springs (Strong, 1972).

The decreases in biomass curves of *Caenis* sp. and Chironomidae indicated primarily emergence, while decreases in Amphipoda indicated mortality. These population decimations all occurred at temperatures near 30° C, implying a direct temperature effect. However, data from separate habitats indicated a more complex system. Ambient channel amphipods were densest in pool areas; in +6 C channels there were never amphipods in pool areas. This may have been attributable to low dissolved oxygen concentrations combined with elevated temperature in these areas and/or possible greater fish predation. On rock areas, amphipod densities attained highest levels in +2 C and +4 C channels, indicating a positive response to temperature up to the +6 C level in these areas. Possibly, amphipods were also best able to escape fish predation among rocks. The above results demonstrated the need for a more detailed study of amphipod populations in each habitat.

Ephemeroptera

The two dominant Ephemeroptera genera found in the experimental channels, *Hexagenia* and *Caenis*, are widely distributed in North America (Edmunds *et al.*, 1976). The *Hexagenia* life cycle is typically univoltine, as is that of *Caenis* spp. in the northern part of their range (Edmunds *et al.*, 1976). However, sporadic *Caenis* emergence close to but not synchronized with the primary one might indicate the potential for multivoltine life cycles in the southern part of their range.

Temperature has been shown to affect mayfly emergence time (Nebeker, 1971), as well as growth and development (Sweeney, 1976). The emergence of *Caenis* at different times in different temperature treatments demonstrated the influence of increased temperature on these organisms. Observation of final nymphal exuviae on the water surfaces of the channels determined that in early April, emergence from the +4 and +6 C treatments occurred approximately ten days before emergence from the ambient and +2 C treatments. The second generation's emergence began in early June in all treatments but ambient. This second generation was less synchronized in its emergence in heated channels than in ambient, extending from early June through August (Wrenn, *et al.*, 1978). The potential for multivoltinism was evident in these warmest channels.

Recruitment in all but the warmest channels occurred primarily in pool areas and on rock areas. The data do not indicate whether this lack of recruitment in the +6 C channels was caused by non-viable eggs, newly hatched nymphs unable to survive the increased temperature, or predation. Except in ambient channels, no recruitment occurred along walls; rather, more mature populations of fewer, larger nymphs were observed on walls oftener than in other areas, particularly toward the end of the sampling period. Since *Caenis* lay their eggs at the water surface, young nymphs would likely be found in pools and rocks at the bottom surface of the channels. Slightly increased population densities along walls could have been expected as nymphs grew and moved out of the areas in which they had hatched. Protection from fish predation along walls of the experimental channels was predicted from earlier studies (unpublished data).

Differences in density and dry weight from treatment during the sampling period occurred primarily beacuse of life-cycle differences. Because ambient channel populations matured more slowly than those in heated channels, their weights were low during the middle of the experiment. With maturity, these ambient-channel populations rallied, surpassing the others, which declined. In the two warmest treatments, density and biomass levels in August were lower than those seen in any previous month. Presumably, these populations were reduced by the effects of increased temperature and/or fish predation.

Chironomidae

Chironomidae are ubiquitous components of freshwater ecosystems, with world-wide distribution; their taxonomic diveristy precludes a detailed species list except in studies devoted to a family or any one of the subfamilies.

Few attempts have been made to determine effects of increased temperature on chironomidae populations, probably because of the aforementioned taxonomic problems. Laboratory studies that have been conducted involved constant temperatures. Harvey (1971) was concerned primarily with the effects of temperature on the sorption of radionuclides, but he observed some population responses. *Glyptotendipes paripes* larvae showed an increased rate of emergence and increased numbers of adults with temperature elevation from 21° to 31° C. Nebeker (1973) found that development rate in *Tanytarsus dissimilis* increased at temperatures ranging from 21° to 28° C; however, an increase in temperature to 32° C brought no further acceleration. Ryals and Ingram (1973) studied the interaction of temperature and day-length on several midge species. They observed development rates and responses to different photoperiods to be markedly influenced by temperature.

Assuming that declines in density and dry weight were indicative of the emergence period, chironomid emergence from +4 and +6 C channels occurred in early June following temperature increases from 23° to 30° C and 22° to 29° C, respectively, during the preceding month. These temperatures are within the range proposed by Harvey (1971) at which the emergence rate of *G. paripes* increased.

Although numerous chironomid species with overlapping emergence periods were present in the experimental channels, distinct periods of peak biomass varied with treatment. Mid-summer maximum biomass in the two warmest treatments occurred in June, approximately one month earlier than that in +2 C channels, which in turn preceded that in ambient channels by a month.

Chironomid emergence, indicated by density declines, varied with habitat. Mid-summer emergence from pools in the two warmest treatments began in June, approximately one month earlier than in +2 C channels, which in turn preceded emergence in ambient channels by a month. Declines in density on rocks and along walls did not demonstrate the same relationship to treatment. These chironomid results differed from *Caenis* emergence, which indicated treatment effects during the emergence period in all three habitats. Chironomids in rock areas did evidence a treatment effect on densities at the end of May, when population size was positively correlated with rise in temperature; however this was the only treatment effect noted outside of pool areas. It is possible that chironomid species composition was different enough in the three habitats that responses to heat varied. Tanypodinae were often the prevalent sub-family in pool areas but not on rocks or walls. Another possibility is that because temperature in pool sediments was generally lower than that on walls and rocks (up to approximately 3° C lower, especially at lower ends of channels) emergence in cooler treatments lagged somewhat behind that in the warmest channels. Only further studies could elucidate the relative sensitivity to temperature of the various chironomid species present in the channels.

These treatment effects indicated different food resources for foraging fish. Because pool areas were of greatest importance to total area and because greatest chironomid biomass per unit area was in these areas (up to 2 gm m^{-2}) effects on Chironomidae might have had greater influence on fish production than those on any other single macroinvertebrate group.

Hirudinea

Leeches are commonly found in ponds, marshes, lakes, and slow streams especially in the northern half of the United States (Pennak, 1953). Treatment effects in this group were so infrequent that one might conclude that those differences detected did not greatly influence fish production. In terms of dry-weight biomass, these organisms at times contributed a major portion to the whole, especially in pool areas (ca. 3 gm m^{-2} in ambient channels in May). However, hirudinid turnover rates are slow relative to most other organisms [illegible] channels. *Erpobdella* spp. have been shown to have a two-year life cycle with breeding occurring at the end of the second year (Elliott, 1973; Aston and Brown, 1975). Because *Helobdella* spp. typically have only two generations per year, with one generation over-wintering (Davies and Reynoldson, 1975), standing-stock biomass utilized by fish would not be quickly replaced. The tapering off of hirudinid populations in all channels toward the end of the sampling period was probably due to the effects of fish predation.

Other Macroinvertebrates

Oligochaetes were treated only perfunctorily because handling them with the care necessary to keep them intact for weighing would have required an inordinate amount of time. Because it is possible that they formed an important part of the bluegill diet, they were accounted for among total macroinvertebrates. Although treatment effects were not analyzed statistically at the end of the sampling period, there were at least 10 times as many oligochaetes in ambient channels as in heated channels. This effect may have been caused by heat directly, by fish predation, by oxygen depletion, or by a combination of these factors precipitated by heat elevation.

Libellulids represented a major source of potential fish food in terms of biomass early in the study. Because those nymphs which formed the main component of this biomass were large, they were able to find refuge from large bluegill among rocks; also, they were too large to fall prey to young-of-the-year bluegill. The relative absence of libellulids on walls and in pools was probably due to fish predation. Previous studies showed intensive predation by bluegill on these nymphs (unpublished data). Only temperature elevations above spring ambient temperatures (ca. 21.5° C) elicited a treatment response. Ambient temperatures exceeding 25° C induced no further treatment effect. It is possible that most of the nymphs present in April and May emerged and gave rise to a second generation of nymphs which were small enough to be fed on by young of the year bluegill.

Trichoptera demonstrated a treatment response similar to that of *Caenis* and other organisms; at the end of the study, ambient channels contained significantly larger densities and greater biomass than did any of the heated water channels.

Community Interactions

Few shifts in percent abundance were attributable to temperature treatment. Most such shifts were seasonal although the decimation of amphipod populations in warm channels at the end of the experiment was reflected in their lower percent abundance. Percents dry weight were likewise less affected by treatment than by time. Where libellulids or hirudinids occurred, they usually exerted a profound effect on dry weight composition relative to their numbers. Diversity indices were no more useful than percent composition data in defining treatment effects. Temperature elevation, therefore, did not conspicuously alter community composition.

Although not perceptibly influenced by temperature, a relationship between *Physa* and Amphipoda occurred which might, with further study, be determined as competitive. On rock areas, where densities of both groups were high, this interaction was especially clear (Fig. 28). Both amphipods and physids are generally grazers, although *Crangonyx* sp. is inclined to carnivorism; therefore, their food source is essentially the same. Toward the middle of the sampling period, there were evident increases in numbers of amphipods concurrent with decreases in *Physa* densities. This relationship deteriorated toward the end of the study, however, giving reason for further study at a later time.

The examination of bluegill stomach contents at the termination of the experiment gave an indication of the food supply available in each treatment. Chironomidae pupae were relatively more abundant than larvae in the +6 C channels, while the reverse was true in ambient channels; this implied a higher turnover rate for chironomids in heated channels. The decrease of physids in +6 C pool areas in August (Table A-2) was reflected in their high percent occurrence in fish stomachs. Amphipods, which disappeared from heated channels before August, were not found at all in fish from +6 C channels; probably because *Caenis* and Hydroptilidae were relatively more abundant in cooler channels than in the two warmest channels, they appeared more frequently in fish from these channels. The almost exclusive feeding of bluegill upon physids and chironomidae pupae in the +6 C channels indicated a lack of other food sources caused by earlier predation, or by increased temperature. Chironomidae were the major food source in all treatments at the end of the study.

In summary, the primary effects of long-term temperature elevation upon macroinvertebrates in the biothermal channels were: acceleration of growth and metamorphosis; greater density and biomass during mid-summer; and lower density and biomass in late summer and early fall. Rarely were effects linearly correlated with temperature increase; most frequently, groups of two or three treatments adjacent in terms of temperature responded at the same time. For example, *Caenis* emergence occurred simultaneously from the two warmest treatments about ten days before emerging from the two coolest treatments. Chironomidae peak dry weights in the two warmest treatments were synchronized; those in cooler channels followed in stepwise fashion. Amphipod peak abundance on rock areas occurred in the three warmest treatments a month before occurring in ambient channels.

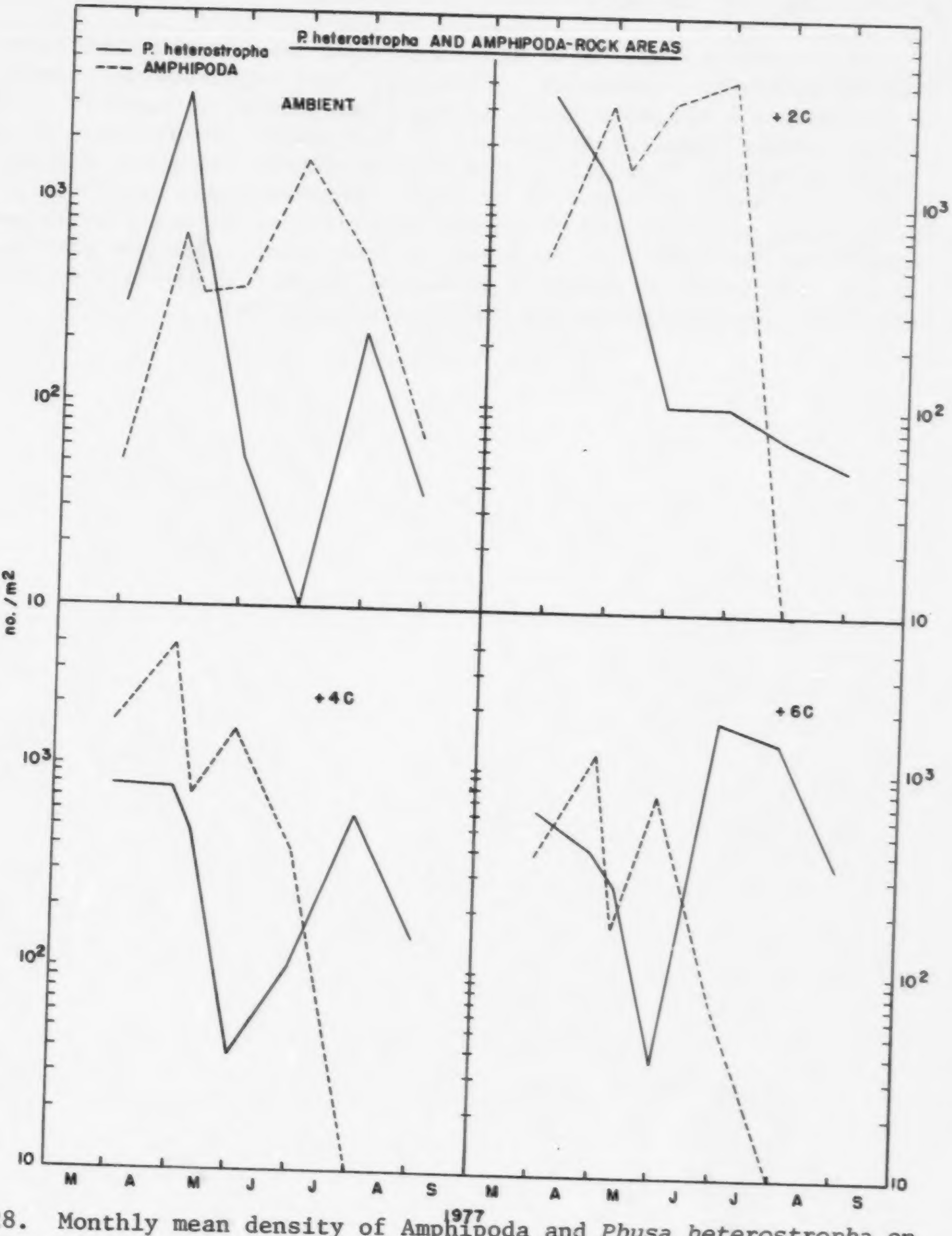

Figure 28. Monthly mean density of Amphipoda and *Physa heterostropha* on rock areas in four temperature treatments (three channels per treatment): A (ambient temperature of Wheeler Reservoir, Tennessee River), and +2°, +4°, and +6° C above ambient.

Finally, temperature affected different habitats unequally, especially for Chironomidae, which were dominant organisms and important fish food. In the density and biomass fluctuations of chironomids, effects were seen only in pool areas, indicating different species composition, or different physico-chemical characteristics generated by temperature treatment.

These effects indicated different food resources available to foraging fish in different treatments. Potential food organisms were most plentiful in all but +2 C channels early in the study, in +2 C channels in mid-summer, and in ambient channels at the end of the study. Total yield of adult and young-of-the-year bluegill at the termination of the study did not reflect final total macroinvertebrate biomass. Neither *Physa heterostropha* nor Chironomidae demonstrated responses to treatment directly correlated with temperature increase. It is possible that these organisms provided the primary food base for bluegill in August in +6 C channels when other macroinvertebrate populations had severely declined.

REFERENCES

Armitage, B. J., T. D. Forsythe, E. B. Rodgers, and W. B. Wrenn. 1978. Browns Ferry Biothermal Research Series I. Colonization by periphyton, zooplankton, and macroinvertebrates. EPA Ecological Research Series, EPA-600/3-78-020, Duluth, MN.

Aston, R. J. and D. J. A Brown. 1975. Local and seasonal variations in populations of the leech *Erpbodella octoculata* (L.) in a polluted river warmed by condenser effluents. Hydrobiologia, Vol. 47(2-3): 347-366.

Berrie, A. D. 1969. Factors affecting growth and reproduction of freshwater Planorbidae in East Africa. Malacologia 9(1): 35-36.

Bovbjerg, Richard V. 1975. Dispersal and dispersion of pond snails in an experimental environment varying to three factors, singly and in combination. Physiological Zool. 48(3): 203-215.

Chernin, Eli. 1967. Behavior of *Biomphalaria glabrata* and of other snails in a thermal gradient. The Journal of Parasitology 53(6): 1233-1240.

Davies, Ronald W. and Trefor B. Reynoldson. 1975. Life history of *Helobdella stagnalis* (L.) in Alberta. Verh. Internat. Verein. Limnol. 19: 282-2839.

DeWitt, Robert M. 1954. Reproduction, embryonic development, and growth in the pond snail *Physa gyrina* SAY. Trans. Amer. Microsc. Soc. 73: 124-137.

Edmunds, George F., Jr., Steven L. Jensen, and Lewis Berner. 1976. The Mayflies of North and Central America. University of Minnesota Press, Minneapolis.

Elliott, J. M. 1973. The life cycle and production of the leech *Eropbdella octoculata* (L.) (Hirudinea: Erpobdellidae) in a lake district stream. J. Anim. Ecol. 42: 437-50.

Harvey, R. S. 1971. Temperature effects on the maturation of midges (Tendipedidae) and their sorption of radionuclides. Health Physics 20: 613-616.

Imhof, Gerhard. 1973. Der einfluss von temperatur and photoperiode auf den lebenszyklus einiger Süsswasserpulmonaten. Malacologia 14: 393-395.

Mathias, Jack A. 1971. Energy flow and secondary production of the amphipods *Hyalella azteca* and *Crangonyx richmondensis occidentalis* in Marion Lake, British Columbia. J. Fish. Res. Board Canada 28: 711-726.

Mattice, Jack. 1975. Effect of constant and varying temperature on egg production of *Lymnaea obrussa* SAY (Mollusca: Gastropoda). Ver. Internat. Verein. Limnol. 19: 3174-3178.

McCraw, Bruce M. 1970. Aspects of the growth of the snail *Lymnaea palustris* (Müller). Malacologia 10: 399-413.

McDonald, S. L. C. 1975. Behavior of the snail *Lymnaea stagnalis* (L.) in relation to temperature. Ph.D. Thesis, U. of Mich. 283 p.

McMahon, Robert F. 1975. Effects of artificially elevated water temperatures on the growth, reproduction and life cycle of a natural population of *Physa virgata* Gould. Ecology 56: 1167-1175.

Michelson, Edward H. 1961. The effects of temperature on growth and reproduction of *Australorbis glabratus* in the laboratory. American Journal of Hygiene 73: 66-71.

Nebeker, Alan V. 1971. Effect of high winter water temperature on adult emergence of aquatic insects. Water Research 5: 777-783.

----------. 1973. Temperature requirements and life cycle of the midge *Tanytarsus dissimilis* (Diptera: Chironomidae). J. Kans. Ent. Soc. 46: 160-165.

Pennak, Robert W. 1953. Fresh-water Invertebrates of the United States. The Ronald Press Company, New York.

Ryals, G. L. and Byron R. Ingram. 1973. Laboratory responses of midge larvae to daylength and temperature (Diptera: Chironomidae). American Zoologist 13: 1341.

Sankurathri, C. S. and J. C. Holmes. 1976. Effects of thermal effluents on the population dynamics of *Physa gyrina* SAY (Mollusca: Gastropoda) at Lake Wabamun, Alberta. Can. J. Zool. 54: 582-590.

Sokal, Robert R. and F. James Rohlf. 1969. Biometry. W. H. Freeman and Company, San Francisco.

Strong, Donald R., Jr. 1972. Life history variation among populations of an amphipod (*Hyalella azteca*). Ecology 53(6): 1103-1111.

Sweeney, Bernard W. 1976. The response of aquatic insects to thermal variation. Ph.D. Thesis, University of Pennsylvania.

Van Der Schalie, Henry and Elmer G. Berry. 1973. Effects of temperature on growth and reproduction of aquatic snails. EPA Ecological Research Series, EPA-R3-73-021.

Wrenn, W. B., B. J. Armitage, E. B. Rodgers, and T. D. Forsythe. 1978. Browns Ferry Biothermal Research Series II. Effects of temperature on bluegill and walleye, and periphyton, macroinvertebrate, and zooplankton communities in experimental ecosystems. EPA Ecological Research Series (in press).

SECTION 8

PERIPHYTON

INTRODUCTION

Thermal additions to ambient water can affect algal populations and community structure in various ways. The optimum temperature threshold for some algal species may be attained resulting in increased phytosynthetic rates and increased growth (Phinny and McIntire, 1965). Concomitantly, increased respiration may also result, negating gains in gross photosynthesis (Phinney and McIntire, 1965; McIntire, 1966). Although generalizations concerning the thermal maxima of taxonomic groupings of algae and other microorganisms can be made (Cairns, 1956; Patrick, 1969; Patrick *et al.*, 1969; Mitchell, 1974), specific thermal limits are species dependent (Stockner, 1967; Stockner, 1968; Patrick, 1969) and sometimes vary among physiological strains of the species as well (Boylen and Brock, 1973; Sorokin, 1971). The thermal tolerance of some algal species may be exceeded resulting in lower phytosynthetic efficiency, encystment, or death (Patrick, 1971; Hickman and Klarer, 1975). Indirect effects, such as increased nutrient recycling or elimination of algal grazers, may enhance the productivity of some algal species. Often, several of these effects will occur simultaneously. All, of course, are governed by the intensity, constancy, and duration of thermal addition as well as site-specific chemical and physical variations which often overrule attempts at generalities.

On a community scale the effects of thermal additions have led to the following: (1) changes in species composition (Boylen and Brock, 1973; Klarer and Hickman, 1975; Hickman and Klarer, 1975); (2) changes in species dominance (Klarer and Hickman, 1975; Hickman and Klarer, 1975); (3) changes in species diversity (Brown, 1973; Klarer and Hickman, 1975); (4) increases in standing crop and growth rate (Bellis, 1968; Brown, 1973; Boylen and Brock, 1973; Hickman, 1974; Klarer and Hickman, 1975; Hickman and Klarer, 1975); (5) acceleration in light-independent succession (Patrick *et al.*, 1969); and/or (6) changes in abundance and nutritional value of algae grazed by herbivores (Hickman and Klarer, 1975; Patrick, 1978).

The purpose of the research presented in this report was to identify the effects of elevated temperature regimens on natural periphyton assemblages found in large outdoor, semi-controlled channels.

MATERIALS AND METHODS

Sampling for periphyton began in late March. Initially, artificial substrates were used (cellulose acetate strips suspended in the water column). However, because of increased losses of these substrates by fish activity during April and May, wall scrapings were later used as a sample source. Normally, three 0.25 m^2 scrapings were taken from the channel walls in the first two pool areas. Samples from the first pool areas were analyzed for fresh weight, freeze-dried weight, and chlorophyll. Samples from the second pool were analyzed for fresh weight, freeze-dried weight, chlorophyll, total protein, total carbohydrates, net oxygen production, tetrazolium violet activity (respiration estimator), and total cellular phosphorus. Additionally, the fresh weight of floating algal mats (algal export) leaving each channel was estimated.

For estimating chlorophyll a*, subsamples were macerated in a tissue grinder with a 90% acetone ($MgCO_3$-saturated) solvent, centrifuged, and decanted. Using a Coleman (Model 111) spectrophotometer, absorbancy values were estimated at 750, 663, 645, and 630 nm. Correction was made for phaeophytin. The concentration of the chlorophylls and phaeophytin were calculated using the formula of EPA (1973).

Total protein was determined by using a modified version of the Lowry and Biuret methods (Dorsey *et al.*, 1975). Total carbohydrates were estimated using a modified version of the anthrone method (Jermyn, 1975). Net oxygen production was estimated *in situ* using light bottles and an incubation period of four hours. Estimates of the activity of the respiratory electron transport system (ETS) were made using tetrazolium violet (Packard *et al.*, 1971). Periphyton subsamples were placed in 300-ml BOD dark bottles, containing channel water and 3 ml of 0.2% w v^{-1} solution of tetrazolium violet, and incubated *in situ* for four hours. Total phosphorus concentratuons in periphyton subsamples were estimated following procedures listed in Standard Methods (see Section 3).

Qualitative microscopic examination of the periphyton from walls, rocks, and floating mats was made to determine community composition and dominance. Incubation (2 hr) of random scrapings with tetrazolium violet (0.2% w v^{-1}) facilitated the subsequent microscopic examination (Packard *et al.*, 1971). Metabolically active cells accumulated the reduced form of this dye - a purple formazan percipitate. A taxon comprising 50% or more of the algal standing crop was referred to as "dominant" while a "subdominant" taxon comprised less than 30% of the standing crop. If two or three were abundant, no one of which clearly exceeded 50% of the standing crop, the term "codominant" was employed. The use of the phrase "change (shift) in dominance" implies a change at the species level, involving the replacement of one dominant taxon by another. "Succession", however, is used to refer to community or assemblage changes, i.e. diatoms → filatamentous green algae → blue-green algae.

RESULTS

A total of 177 taxa of algae were identified, including 53 taxa identified for the first time from the channels during this experiment (Table 34). The 53 newly observed taxa included green algae (28), diatoms (9), and blue-green algae (16). Similarity-matices for five sample dates were created from presence-absence data (Table 34) employing simple matching and Jaccard's coefficients. Cluster analysis was performed on the Jaccard coefficients employing the unweighed pair-group method with arithmetic averages. Resulting phenograms (Fig. 29) indicate that algal assemblages in the +2 and +4 C treatments had the closest similarity for all sampling dates; and that a reversal in the similarities of the algal assemblages in the ambient and +6 C treatments occurred during the study. The assemblage in the +6 C treatment was least similar to the other treatment assemblages during the spring, and the assemblage in the ambient channels was least similar during the summer. A coefficient of cophenetic correlation was calculated for each phenogram to indicate distortion (Fig. 29). Acceptable values were obtained for all sampling dates except those at the end of spring and during the warmest days of summer.

Changes in dominance within the periphyton communities occurred first in the +6 C treatment, and followed later, to varying degrees, in other treatments. Temperature conditions for each treatment and month mentioned below can be determined from Figure 4. During March and early April, *Tetraspora lamellosa* codominated with the winter diatom *Melosira varians* in the ambient channels and with *Oedogonium kurzii* in the +2 C and +4 C channels. However, no significant population of *Tetraspora lamellosa* was found in the +6 C channels, which were dominated by *Stigeoclonium subsecundum*, *Cladophora glomerata*, and *Oedogonium kurzii*. During April, *Oedogonium kurzii* was the dominant alga in the ambient, +2 C, and +4 C channels, forming dense growths on the walls. However, in the +6 C channels *Cladophora glomerata* covered the walls with *Oedogonium kurzii* subdominant. During mid- to late May, *Oedogonium kurzii* dominated the biomass in the ambient channels; however, little metabolic activity was noted. *Cladophora glomerata* was also abundant in these channels with *Characium obtusum* and to a lesser extent *Cymbella minuta* and *Gomphonema parvulum* epiphytic on the older filaments. In the +2 C and +4 C channels *Cladophora glomerata* encircled by *Spirogyra gratiana* and colonized by *Cymbella minuta* and *Gomphonema parvulum*, was dominant; however, much of its former metabolic activity had diminished. *Spirogyra gratiana* and the epiphytic diatoms were highly active. In the +6 C channels a similar situation existed with the addition that a larger number of desmid species were present, while the blue-green algal *Oscillatoria limosa* and *O. amphiba* were subdominant. *Oedogonium kurzii* was still present in large amounts in all the heated channels, however, metabolic tests indicated that it was senescent.

During June, *Spirogyra gratiana* and the *Cymbella-Gomphonema* epiphytes of *Cladophora glomerata* were the most metabolically active dominants in all channels. *Cladophora glomerata* covered extensive areas but had decreased in metabolic activity. *Hydrodictyon reticulatum* contributed the greatest percentage of floating mat biomass in the ambient and +2 C channels, but was not present in significant quantities in the +4 C and +6 C channels. Of the two diatoms epiphytic on *Cladophora glomerata*, *Cymbella minuta* was consistently more numerous. However, in the +6 C channels this was reversed with *Gomphonema parvulum* more numerous. During this sampling period, the largest number of species (53) was identified from all the channels with the green algae contributing the most taxa (31).

During July, *Spirogyra gratiana* was dominant in all treatments, covering walls and rock areas, and forming extensive floating mats. *Cladophora glomerata* and its epiphytic diatoms were still present but had decreased in importance. The blue-green alga *Oscillatora princeps* became an important part of floating mat and attached communities in the +6 C channels.

During August, floating mats of *Spirogyra gratiana*, *Oscillatoria princeps*, and *Cladophora glomerata* were prevalent in all the channels. The number of blue-green algal taxa increased significantly in all channels, many forming a thick, mud-encased scum on the walls. The number of diatoms increased during this month, especially on mud-surfaced walls in the ambient channels.

Monthly treatment means for algal export (floating mats) (Table 2) indicate a maximum for all treatments during June. The +6 C treatment consistently produced the largest monthly biomass (wet weight) of algae and had a five month total 2 to 3 times that of other treatments.

Fresh and dry weight estimates (Tables 36-7) indicate no apparent temperature effects. High variation within and between pools and between channels in a treatment were common for these parameters as well as most of the following. Sample estimates of active chlorophyll, total protein, and total carbohydrates (Tables 38-43) indicated no apparent temperature effects. Total protein, per gram dry weight, decreased in all treatments during the summer. Protein to carbohydrate ratios also decreased toward the end of the summer (Table 44). Total phosphate, per gram dry weight, was significantly different in the +4 and +6 C treatments during the last sampling date (Table 45). Treatment means of assimilation ratios (mg O_2 hr^{-1} mg^{-1} chlorophyll) are presented in Table 47. Only during July were statistically significant differences ($P > .01$) noted. Estimates of ETS (tetrazolium violet) activity (ml O_2 consumed hr^{-1}) are presented in Table 48. Statistically significant ($P > 0.1$) treatment differences were found for the ETS/chlorophyll a* ratios during the last two monthly sampling dates. Step-wise regression procedures (SAS Institute Inc., Raleigh, NC) were performed upon all the variables estimated for the last three monthly sampling dates (7 July, 3 August, and 31 August). A significance level of 0.1 was used as a criterion by which a variable was added to the model. Regression equations for the dependent variables (net oxygen production and ETS activity) are found in Table 49.

DISCUSSION

Although many parameters were estimated, variation of periphyton biomass was too high for statistical comparison among treatments for individual channel sampling locations. However, because a channel's contributions to algal export were derived from the entire channel, variation within treatments for this parameter were comparatively low. In addition, indications of temperature effects from shifts in dominance and community succession were not affected by patchy distributions.

Sampling Variation

One of the most difficult decisions when initiating an experiment is determining the number of samples needed to satisfy both statistical reliability and economic-time practicalities. This problem was made evident during the past several years by macrobenthic workers attempting to determine the number of areal samples needed for a single riffle. Estimates have ranged from a small fraction of the riffle's area to several times the riffle's area.

The number of samples needed for estimating periphyton parameters is no less uncertain. Patchy distributions in many natural habitats are the norm, formed partially by random dispersal of propagules, by macrohabitat variations, and by competition for substrate attachment sites. Compounding this macro-sampling problem is a subsampling problem; subsamples of a periphyton sample will contain varying percentages of actively growing, senescent, and dead algal cells. A subsample used for estimating net oxygen production, therefore, may have little correlation with an estimate of total protein or chlorophyll taken from another subsample. This problem can be partially circumvented by making multiple estimates from the same subsample (e.g., determining net oxygen production, then extracting the chlorophyll, then measuring total protein in the remaining residue). However, this also has obvious limitations.

While the primary objective of this experiment was to determine the effect of elevated temperatures on various periphyton parameters; the results indicate that variation between temperature treatments was usually less than variation within and between pools and among channels in a treatment. This was especially true for biomass estimates from wall scrapings. Estimates of physiological parameters (e.g., mg O_2 produced/mg chl, etc.) were no more illuminating. Obviously, any temperature effects on wall periphyton were masked by patchy distribution, subsampling deficiencies, and/or other factors.

One of these "other" factors affecting periphyton density on the channel walls was shading by algal mats. Floating algal mats, composed of filamentous green and blue-green algae, were formed by contributions from the channel walls (*Oedogonium*, *Cladophora*, and *Hydrodictyon*), from the rock areas (*Cladophora* and *Spirogyra*), and from the pool sediment surface (*Spirogyra* and *Oscillatoria*). Additional growth occurred along the edges of the mats. When located near a wall or over a pool or a rock area, the mats effectively depressed phytosynthetic activity for attached algae below them. This decreased growth along one section of the channel and allowed growth along another section, thus increasing the variation in biomass.

Thermal Effects

During the present study, two effects of increased temperature on the algal community were noted. First, a greater monthly and total biomass of algal export was observed in the +4 C and +6 C treatments versus the +2 C and ambient treatments. Algal export provided the best indication of thermal enhancement. Because of the extreme patchiness of the attached wall communities, no definite thermal effects on standing crop for this substratum could be discerned. Second, within both the floating mats and the wall communities, succession and shifts in dominance were accelerated in the +6 C channels.

More algal biomass was exported monthly from the +6 C treatment channel (Table 2). Converting to dry weight, the total yield ranged from ca. 1600 kg ha^{-1} in the ambient channels to ca. 4100 kg ha^{-1} in the +6 C channels. Examination of nutrient data indicates sufficient total ortho-phosphorus (0.03-0.10 ppm) and nitrate (0.02-0.66 ppm) concentrations for algal blooms. Because the experimental channels are a flow-through system, these nutrients were supplied constantly. Nutrient rich sediment inputs following heavy rains and anaerobic release from pool sediments provided additional nutrient sources to sustain blooms. Luxuriant growths of algae are typical of many canals and channels. Oksiyuk (1969, as cited in Coutant, 1970) stated that these growths are a general problem of canals occurring wherever growth supporting nutrients are present in sufficient quantities. Thus, the differences in magnitude of algal export among treatments were attributed to temperature related stimulation. However, the magnitude of yield in all treatments was attributed to temperature and continuous inputs of nutrients in sufficient concentrations to maintain growth.

The influence of thermal increments was evidenced in species composition and dominance during the first sampling in March. *Tetraspora lamellosa*, an early spring bloomer, and *Melosira varians*, a winter dominant, were codominant only in the ambient channels. These species were the standard early spring dominants during the previous two years. However, in the +2 C and +4 C channels, *Melosira varians* declined while *Oedogonium kurzii* was codominant with *Tetraspora lamellosa*. In the +6 C channels *Tetraspora lamellosa* failed to establish any significant populations. It might be postulated that the filamentous green algae which dominated the +6 C channels at this time out-competed the *Tetraspora lamellosa* for substratum space or that extracellular substances inhibited colony formation. Although these mechanisms might have been contributory, temperature increases appear to be a direct factor affecting the *Tetraspora lamellosa* in the +6 C channels.

The presence of significant populations of *Cladophora glomerata* in the +6 C channels during March was evidence of accelerated succession. *Cladophora glomerata* normally was dominant during May in ambient waters.

The temperature during late March in the +6 C channels was 20-22C, similar to the optimum growth temperature (22-23C) for *Cladophora glomerata* noted by Gerloff and Fitzgerald (1976). *Cladophora glomerata* was persistent, maintaining a significant, if not active, biomass throughout the spring and summer months. Even when metabolic activity decreased, as indicated by tetrazolium violet reduction, *Cladophora glomerata* filaments provided a substratum for *Characium obtusum*, *Gomphonema parvulum*, and *Cymbella minuta* populations which exhibited high metabolic activity during late spring and early summer.

Oedogonium kurzii was another persistent alga. Although tests indicated little metabolic activity after mid-May, filaments were commonly found in wall scrapings for the entire study period. This species also provided a substratum for diatoms, green algae, and later some smaller filamentous blue-green algae. Previous observations of *Oedogonium kurzii* in the channels, indicated population maxima during the winter months and again in the spring in ambient waters. In this study, *Oedogonium kurzii* decreased in metabolic importance earlier in the heated channels.

The summer dominant, *Spirogyra gratiana*, assumed importance in the heated channels 2-3 weeks earlier than in the ambient channels. As opposed to *Oedogonium kurzii* and *Cladophora glomerata*, *Spirogyra gratiana* filaments did not support an epiphytic flora. A mucilaginous sheath barred such exploitations. The optimum temperature threshold for phytosynthesis and growth was reached in the heated channels during May, with *Spirogyra gratiana* continuing as the dominant or codominant alga throughout the summer. The maximum lethal temperature (44C) cited for this alga (DeVries, 1870) was never attained.

The filamentous blue-green algae also appeared initially in the heated channels and became subdominant or codominant in those channels prior to being prevalent in the ambient channels. *Oscillatora limosa* and *O. amphiba* became subdominant during May in the +6 C channels. *Oscillatoria princeps* replaced *O. limosa* and *O. amphiba* as the dominant blue-green in the +6 C channels. As the summer progressed, the +4 C, +2 C, and finally the ambient channels developed large populations of *O. princeps*. Similarly, the blue-green dominated, mud-encased scum on the channel walls developed first in the +6 C channels and last in the ambient channels. The free floating blue-green filaments harbored no epiphytic flora; however, the mud-encased scum did provide a substratum for several diatom species.

Changes in the composition of algal communities may directly affect the growth, reproduction, or survival of herbivores and ultimately carnivores. Certain groups of algae have generally higher prey value than others (Bush *et al.*, 1974; Patrick, 1978), e.g. diatoms > green algae > blue-green algae. Even within these general groups some genera are more favorable prey than others in terms of availability and nutritional value (Patrick, 1978), e.g. *Navicula-Nitzschia* > *Cocconeis-Melosira*, and *Cladophora* > *Spirogyra*. During this experiment, the early disappearance of *Tetraspora lamellosa* in the +6 C channels, replaced by filamentous green algae and attached diatoms, was not detrimental to the herbivores either in terms of nutrition or availability. The dense mucilage which encloses *Tetraspora* cells presumably inhibited grazing. Later in the spring, the epiphytic diatoms on *Cladophora glomerata* and *Oedogonium kurzii* filaments provided a good prey source for herbivores. The major nutritional impact of accelerated succession on herbivores occurred during July and August when *Spirogyra gratiana* and *Oscillatoria princeps* began to dominate the algal communities. These taxa offered low prey value and, additionally, harbored few epiphytes. This negative impact was partially offset during August by an increase in numbers and taxa of diatoms on the sediment layers on walls, pools, and rock areas. In general, the accelerated succession and increased biomass accumulation in the heated channels appeared to increase the herbivore food supply during the spring and early summer, but appeared to decrease the supply temporarily during late summer.

A general effect of temperature on periphyton communities was to accelerate the timing of shifts in dominance or succession. All algal species which developed populations in +2 C, +4 C, and +6 C channels eventually developed populations in the ambient channels. There were no thermophilic species noted for this experiment which developed only in the warmest channels. The maximum temperatures attained (< 36C) were probably not high enough to accomodate or enhance such taxa. Another general effect was an increase in biomass in the warmest channels. Although wall biomass was not a good indicator of this due to sloughing, shading, grazing, etc., algal export, fueled by inputs from the walls, pool sediments, and rock areas, did provide a clear indication of increased biomass accumulation. Factors other than temperature, such as extracellular metabolites (Keating, 1976) and mega- and micronutrients (Patrick, 1978) can cause shifts in species composition and increases in standing crop. However, the semi-controlled nature of the biothermal channels (identical flow rates, substrate types, nutrient inputs, etc.) precluded many of these factors. Thus it was concluded that temperature increments above ambient were responsible for the nonsynchronous population shifts and the increased accumulation and export of algal biomass.

REFERENCES

Bellis, V. J. 1969. Unialgal cultures of *Cladophora glomerata* (L.) Kütz. I. Response to temperature. *J. Phycol.* 4: 19-23.

Boylen, C. W. and T. D. Brock. 1973. Effects of thermal additions from the Yellowstone geyser basins on benthic algae of the Firehole River. *Ecology*, 54: 1282-1291.

Brock, T. D. and J. Hoffman. 1974. Temperature optima of algae living in the outfall of a power plant on Lake Monona, Wisc., *Wisc. Acad. Sci. Arts Letts.*, 62: 195-203.

Brown, S. D. 1973. Site variation in littoral periphyton populations: correlation and regression with environmental factors. *Int. Rev. ges. Hydrobiol.*, 58: 437-461.

Bush, R. M., E. B. Welch, and B. W. Mar. 1974. Potential effects of thermal discharge on aquatic systems. *Envir. Sci. Tech.*, 8: 561-568.

Cairns, J., Jr. 1956. Effects of increased temperature on aquatic organisms. *Indus. Wastes*, 1: 150-152.

Coutant, C. C. 1970. Biological aspects of thermal pollution I. Entrainment and discharge canal effects. pp. 341-381, CRC Crit. Rev. Envir. Control.

DeVries, H. 1870. Materiaux pour la connaissance de l'influence de la temperature sur les plantes. *Arch. Neer. Sci. Exactes Natur.*, 5: 385-401.

Farrell, J. and A. Rose. 1967. Temperature effects on microorganisms. *Ann. Rev. Microbiol.*, 21: 101-120.

Gerloff, G. C. and G. P. Fitzgerald. 1976. *The nutrition of Great Lakes Cladophora*. EPA-600/3-76-044, Envir. Res. Lab, Duluth, MN.

Hickman, M. 1974. Effects of discharge of thermal effluent from a power station on Lake Wabamun, Alberta, Canada - The epipelic and epipsammic algal communities. *Hydrobiol.*, 45: 199-215.

Hickman, M. and D. M. Klarer. 1975. The effects of the discharge of thermal effluents from a power station on the primary productivity of an epiphytic community. *Br. Phycol. J.*, 10: 81-91.

Keating, K. I. 1976. *Algal metabolite influence on bloom sequence in eutrophied freshwater ponds*. EPA-600/3-76-081, EPA, Corvallis, OR.

Klarer, D. M. and M. Hickman. 1975. The effect of thermal effluent upon the standing crop of an epiphytic algal community. *Int. Revue ges. Hydrobiol.*, 60: 17-62.

McIntire, C. D. 1966. Some factors affecting respiration of periphyton communities in lotic environments. *Ecology*, 47: 919-930.

Mitchell, R. 1974. The evolution of thermophily in hot springs. *Quart. Rev. Biol.*, 49: 229-242.

Packard, T. T., M. L. Healy, and F. A. Richards. 1971. Vertical distribution of the activity of the respiratory electron transport system in marine plankton. *Limnol. Oceanogr.*, 16: 60-70.

Patrick, R. 1969. Some effects of temperature on freshwater algae, In: *Biological Aspects of Thermal Pollutions*. Symposium Proceedings, Portland, OR, June 3-5, 1969. pp. 161-198. Vanderbilt Univ. Press, Nashville.

Patrick, R. 1971. The effects of increasing light and temperature on the structure of diatom communities. *Limnol. Oceanogr.*, 16: 405-421.

Patrick, R. 1974. Effects of abnormal temperatures on algal communities. In: *Thermal Ecology*, J. W. Gibbons and R. R. Sharitz (eds.). pp. 335-349. U.S. ERDA, Washington, D.C.

Patrick, R. 1978. Effects of trace metals in the aquatic ecosystem. *Amer. Sci.*, 58: 185-191.

Patrick, R., B. Crum, and J. Coles. 1969. Temperature and manganese as determining factors in the presence of diatom or blue-green algal floras in streams. *Proc. Nat. Acad. Sci.*, 64: 472-478.

Phinney, H. K. and C. D. McIntire. 1965. Effect of temperature on metabolism periphyton communities developed in laboratory streams. *Limnol. Oceanogr.* 10: 341-344.

Sorokin, C.. 1971. Calefaction and phytoplankton. *Bioscience*, 21: 1153-1159.

Stockner, J. G. 1967. Observations of thermophilic algal communities in Mount Rainier and Yellowstone National Park. *Limnol. Oceanogr.* 12: 13-17.

Stockner, J. G. 1968. The ecology of a diatom community in a thermal stream. *Br. Phycol. Bull.*, 3: 501-514.

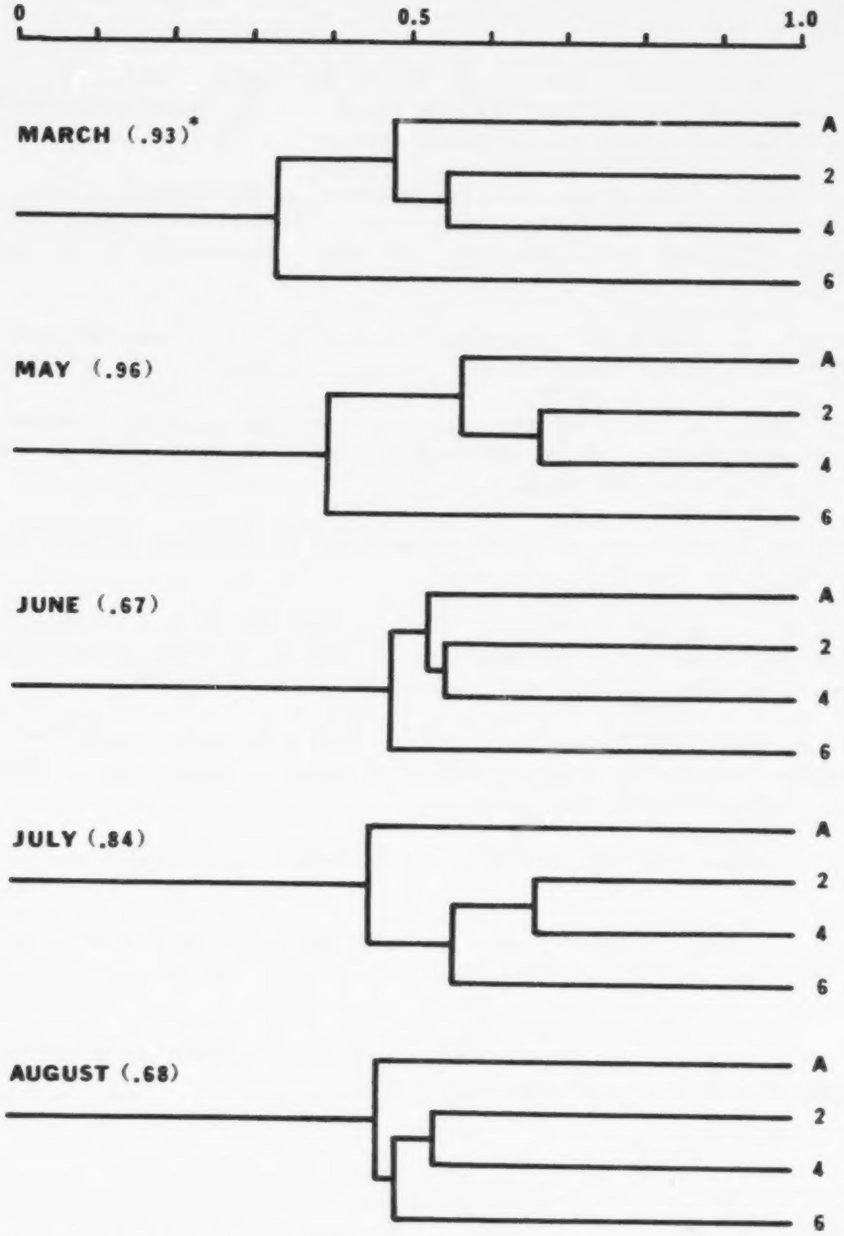

Figure 29. Phenograms derived from periphyton presence-absence data (Jaccard coefficients - unweighed pair group method with arithmetic averages; * - coefficient of cophenetic correlation).

TABLE 34. PERIPHYTON PRESENCE-ABSENCE DATA FROM MONTHLY WALL SCRAPES.

Class/Species	Date: Treatment:	March A	March +2	March +4	March +6	May A	May +2	May +4	May +6	June A	June +2	June +4	June +6	July A	July +2	July +4	July +6	August A	August +2	August +4	August +6
Chlorophyceae																					
*Characium obtusum						X				X	X	X	X								
*Characium sp.						X			X	X	X	X	X								
Chlamydomonas sp.																	X				
Cladophora glomerata				X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
*Closterium ehrenbergii var. malinvernianum											X		X								
*Closterium littorale												X	X								
Closterium lunula									X	X		X	X		X						
*Closterium parvulum									X						X						
Cosmarium botrytis var. tumidum									X			X						X			X
Cosmarium exiguum				X														X		X	X
*Cosmarium granatum									X			X	X	X							X
*Cosmarium impressulum																		X			
Cosmarium margaritatum							X														

* Periphyton species identified for the first time during this experiment.

(continued)

TABLE 34 (continued).

Class/Species	Date:	March				May				June				July				August			
	Treatment:	A	+2	+4	+6	A	+2	+4	+6	A	+2	+4	+6	A	+2	+4	+6	A	+2	+4	+6
Cosmarium ochthodes var. amoebum									X												X
*Cosmarium subcrenatum									X												
*Cosmarium tinctum							X														
***Cosmarium** sp.												X	X								
Hydrodictyon reticulatum						X		X	X	X	X	X	X								
Oedogonium kurzii		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
Pandorina morum												X	X								
*Pediastrum duplex var. clathratum														X	X						
*Pediastrum duplex var. duplex									X				X								
*Pediastrum duplex var. gracilimum												x									
Pediastrum duplex var. reticulatum												X									
*Pediastrum sculpatum												X									

* Periphyton species identified for the first time during this experiment.

(continued)

TABLE 34 (continued)

Class/Species	Date: Treatment:	March A	March +2	March +4	March +6	May A	May +2	May +4	May +6	June A	June +2	June +4	June +6	July A	July +2	July +4	July +6	August A	August +2	August +4	August +6
*Pediastrum simplex var. duodenarium												X					X				
*Pediastrum simplex var. simplex											X	X					X				
*Pediastrum tetras												X									
*Pediastrum sp.												X									
*Pleurotaenium maximum													X						X		
*Pleurotaenium trabecula												X					X				
Protoderma viride		X							X												
*Scenedesmus acuminatus													X								
*Scenedesmus bujuga var. alterans													X								
*Scenedesmus dimorphus																				X	
Scenedesmus quadricauda												X	X		X	X	X		X		X
*Sphaerocystis schroeteri												X									
Spirogyra gratiana					X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Spirogyra sp.-1						X	X	X		X									X	X	

* Periphyton species identified for the first time during this experiment.

(continued)

TABLE 34 (continued).

Class/Species	Date:	March				May				June				July				August			
	Treatment;	A	+2	+4	+6	A	+2	+4	+6	A	+2	+4	+6	A	+2	+4	+6	A	+2	+4	+6
*Spirogyra sp.-2										X											
*Stigeoclonium subsecundum		X	X		X					X			X			X		X		X	
*Tetraedron pentaedricum									X												
Tetraspora lamellosa		X	X	X																	
*Ulothrix sp.									X		X	X	X			X	X			X	
Bacillariophyceae																					
Achnanthes exigua					X																
*Achnanthes sp.											X										
Cocconeis disculus				X																	
Cymbella affinis					X																
Cymbella minuta						X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Cymbella postrata			X																		
Cymbella tumida		X	X			X	X														
Diatoma hiemale					X																
*Eunotia sp.								X													

* Periphyton species identified for the first time during this experiment.

(continued)

TABLE 34 (continued).

Class/Species	Date: Treatment:	March A	March +2	March +4	March +6	May A	May +2	May +4	May +6	June A	June +2	June +4	June +6	July A	July +2	July +4	July +6	August A	August +2	August +4	August +6
*Fragilaria capucina							X	X	X	X	X	X	X		X	X	X	X	X	X	
Fragilaria crotonensis		X				X	X	X	X	X		X		X			X	X			
Gomphonema angustatum										X	X	X	X	X	X	X	X	X			
Gomphonema parvulum		X		X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
*Gyrosigma kutzingii		X	X	X														X		X	X
*Gyrosigma scalproides								X		X	X		X		X						
Melosira granulata		X	X	X	X	X	X	X													
Melosira granulata var. angustissima		X				X		X	X	X	X	X	X	X	X	X	X		X	X	X
Melosira varians		X	X	X	X	X	X	X	X	X	X	X	X					X			X
*Navicula capitata		X	X	X	X																
*Navicula confervacea																		X	X	X	X
Navicula mutica																		X			
Navicula radiosa				X	X				X			X									
*Navicula viridula var. rostellata																		X			

*Periphyton species identified for the first time during this experiment.

(continued)

TABLE 34 (continued).

Class/Species Date:	March				May				June				July				August			
Treatment:	A	+2	+4	+6	A	+2	+4	+6	A	+2	+4	+6	A	+2	+4	+6	A	+2	+4	+6
Navicula sp.									X	X	X	X					X	X	X	
Nitzschia acicularis	X								X		X	X					X			
Nitzschia dissipata	X		X														X		X	X
Nitzschia palea											X	X					X		X	X
Nitzschia tryblionella																X			X	X
Opeophora martyi																X				
Rhoicosphenia curvata					X															
Stauroneis anceps	X																			
*Surirella linearis												X	X	X	X	X		X	X	X
Synedra actinastroides					X	X	X		X											
Synedra acus	X		X						X	X	X	X								
Synedra rumpens													X							
Synedra ulna							X	X					X	X	X	X	X	X	X	X
Synedra ulna var. longissima					X	X	X	X	X	X	X	X								

* Periphyton species identified for the first time during this experiment.

(continued)

TABLE 34. (continued).

Class/Species	Date:	March				May				June				July				August			
	Temperature:	A	+2	+4	+6	A	+2	+4	+6	A	+2	+4	+6	A	+2	+4	+6	A	+2	+4	+6
Cyanophyceae																					
*Aphanocapsa pulchra					X																
*Aphanothece gelatinosa																		X	X		
*Calothrix stellaris		X	X	X																	
*Chroococcus sp.			X																		
*Lyngbya gardneri		X	X	X		X	X	X		X	X	X	X	X	X	X	X	X	X	X	X
*Lyngbya major																			X	X	X
*Lyngbya nigra																		X	X		
*Lyngbya spirulinoides			X	X																	
*Lyngbya versicolor																		X	X	X	X
*Lyngbya sp.																			X	X	
Merismopedia sp.											X	X	X	X				X	X	X	X
*Oscillatoria amphibia						X	X	X	X				X	X	X						
*Oscillatoria decolorata																				X	
***Oscillatoria limosa**							X	X	X		X	X	X		X	X	X	X	X	X	X

*Periphyton species identified for the first time during this experiment.

(continued)

TABLE 34 (continued).

Class/Species	Date:	March				May				June				July				August			
	Treatment:	A	+2	+4	+6	A	+2	+4	+6	A	+2	+4	+6	A	+2	+4	+6	A	+2	+4	+6
Oscillatoria nigra																		X	X	X	X
Oscillatoria princeps												X	X		X	X	X	X	X	X	X
*Oscillatoria proboscidea																			X		
*Oscillatoria sancta																	X				
*Oscillatoria subbrevis			X	X	X															X	

*Periphyton species identified for the first time during this experiment.

TABLE 35. ALGAL EXPORT (KG FRESH WEIGHT) - 1977.

TEMPERATURE REGIMEN		APRIL	MAY	JUNE	JULY	AUGUST	TOTAL KG CHANNEL^{-1}	TOTAL KG HA^{-1}
Ambient	$\bar{x}$[a]	4.3	66.4	111.3	53.1	23.1	258.2	5379
	s[b]	2.1	32.4	14.0	7.4	3.4		
+2 C	$\bar{x}$	1.2	14.2	81.6	71.6	36.8	205.4	4279
	s	0.6	7.0	41.4	10.5	3.0		
+4 C	$\bar{x}$	12.4	60.4	109.7	91.8	69.5	343.8	7163
	s	14.5	63.5	28.9	15.8	15.7		
+6 C	$\bar{x}$	34.1	85.3	306.1	123.7	109.5	658.5	13719
	s	18.8	41.2	59.5	11.2	13.6		

[a] Treatment mean (n = 3).

[b] Standard deviation (±).

TABLE 36. PERIPHYTON FRESH WEIGHT (GM M^{-2}) - POOL 2.

TEMPERATURE REGIMEN	1977:	6-20	7-06	7-21	8-03	8-16	8-31
AMBIENT	$\bar{x}$[a]	51	60	33	67	58	45
	s[b]	38	19	9	49	29	7
+2 C	$\bar{x}$	49	112	57	90	53	68
	s	27	58	30	48	6	41
+4 C	$\bar{x}$	39	99	88	110	102	92
	s	24	37	36	32	34	11
+6 C	$\bar{x}$	23	93	69	89	45	48
	s	17	91	20	13	19	21

[a] Treatment mean (n = 9).

[b] Standard deviation (±).

TABLE 37. PERIPHTYON DRY WEIGHT (GM M^{-2}) - POOL 2.

TEMPERATURE REGIMEN	1977:	6-20	7-06	7-21	8-03	8-16	8-31
AMBIENT	$\bar{x}$[a]	7	11	9	21	14	12
	s[b]	5	5	2	15	6	4
+2 C	$\bar{x}$	8	24	14	30	15	21
	s	4	7	5	20	5	11
+4 C	$\bar{x}$	6	27	23	31	25	16
	s	4	11	7	7	8	5
+6 C	$\bar{x}$	6	18	16	28	10	9
	s	4	13	5	8	6	4

[a] Treatment mean (n = 9).

[b] Standard deviation (±).

TABLE 38. PERIPHYTON CHLORPHYLL A* (MG M^{-2}) - POOL 1.

TEMPERATURE REGIMEN	1977:	5-12	5-23	6-09	6-20	7-06	7-21	8-03	8-16	8-31
AMBIENT	$\bar{x}$ [a]	132	56	117	75	18	40	95	100	56
	s [b]	89	37	17	66	11	18	44	90	52
+2 C	$\bar{x}$	108	79	126	51	70	68	69	70	68
	s	81	69	96	52	36	59	28	40	89
+4 C	$\bar{x}$	38	104	46	62	144	81	160	153	158
	s	11	68	41	51	146	20	82	51	22
+6 C	$\bar{x}$	52	99	54	34	44	109	61	50	80
	s	16	36	23	21	13	17	17	17	48

[a] Treatment mean (n = 9).

[b] Standard deviation (±).

TABLE 39. PERIPHYTON CHLOROPHYLL A* (MG M^{-2}) - POOL 1.

TEMPERATURE REGIMEN	1977:	5-12	5-23	6-09	6-20	7-06	7-21	8-03	8-16	8-31
AMBEINT	$\bar{x}$ [a]	157	90	148	48	36	30	51	90	50
	s [b]	22	32	190	45	13	11	42	50	10
+2 C	$\bar{x}$	83	169	45	42	92	63	55	60	76
	s	42	102	46	34	58	44	9	17	41
+4 C	$\bar{x}$	77	114	57	31	105	100	115	172	130
	s	60	65	36	24	44	53	48	121	36
+6 C	$\bar{x}$	113	258	124	21	104	88	116	59	78
	s	121	155	114	17	109	18	29	18	29

[a] Treatment mean (n = 9).

[b] Standard deviation (±).

TABLE 40. PERIPHYTON TOTAL PROTEIN (MG M^{-2}) - POOL 2.

TEMPERATURE REGIMEN	1977:	6-09	6-20	7-06	8-03	8-31
AMBIENT	$\bar{x}$ [a]	631	465	320	748	307
	s [b]	206	314	70	631	77
+2 C	$\bar{x}$	358	534	658	646	487
	s	67	290	275	63	348
+4 C	$\bar{x}$	479	308	806	774	394
	s	250	349	231	91	115
+6 C	$\bar{x}$	547	250	852	886	249
	s	293	172	703	247	97

[a] Treatment mean (n = 9).

[b] Standard deviation (±).

TABLE 41. PERIPHYTON TOTAL PROTEIN / DRY WEIGHT (GM GM^{-1}) - POOL 2.

TEMPERATURE REGIMEN	1977:	6-09	6-20	7-06	8-03	8-31
AMBIENT	$\bar{x}$ [a]	- [c]	.066	.036	.033	.027
	s [b]	-	.015	.020	.015	.006
+2 C	$\bar{x}$	-	.066	.027	.027	.023
	s	-	.015	.005	.006	.006
+4 C	$\bar{x}$	-	.050	.038	.023	.027
	s	-	.028	.019	.006	.006
+6 C	$\bar{x}$	-	.043	.050	.033	.027
	s	-	.012	.030	.015	.006

[a] Treatment mean (n = 9).

[b] Standard deviation (±).

[c] Data not available.

TABLE 42. PERIPHYTON TOTAL CARBOHYDRATE (GM M^{-2}) - POOL 2.

TEMPERATURE REGIMEN	1977:	7-06	8-03	8-31
AMBIENT	$\bar{x}$ [a]	2.15	3.28	2.57
	s [b]	.33	2.55	1.21
+2 C	$\bar{x}$	4.57	2.04	2.55
	s	2.99	.82	.94
+4 C	$\bar{x}$	3.51	4.48	3.73
	s	1.51	2.30	1.82
+6 C	$\bar{x}$	2.69	2.70	2.51
	s	2.69	.85	1.29

[a] Treatment mean (n = 9).

[b] Standard deviation (±).

TABLE 43. PERIPHYTON TOTAL CARBOHYDRATE / DRY WEIGHT (GM GM^{-1}) - POOL 2.

TEMPERATURE REGIMEN	1977:	7-06	8-03	8-31
AMBIENT	$\bar{x}$ [a]	.16	.14	.22
	s [b]	.02	.03	.09
+2 C	$\bar{x}$	.18	.08	.13
	s	.11	.05	.03
+4 C	$\bar{x}$	.13	.14	.23
	s	.01	.04	.09
+6 C	$\bar{x}$	.14	.10	.27
	s	.06	.01	.08

[a] Treatment mean (n = 9).

[b] Standard deviation (±).

TABLE 44. PERIPHYTON TOTAL PROTEIN / TOTAL CARBOHYDRATE - POOL 2.

TEMPERATURE REGIMEN	1977:	7-06	8-03	8-31
AMBIENT	$\bar{x}$[a]	.15	.27	.13
	s[b]	.01	.11	.04
+2 C	$\bar{x}$	.19	.35	.18
	s	.11	.14	.07
+4 C	$\bar{x}$	.25	.20	.12
	s	.09	.10	.07
+6 C	$\bar{x}$	.37	.35	.12
	s	.13	.16	.05

[a] Treatment mean (n = 9).

[b] Standard deviation (±).

TABLE 45. PERIPHYTON TOTAL PHOSPHATE / DRY WEIGHT (GM GM^{-1}) - POOL 2.

TEMPERATURE REGIMEN	1977:	7-06	8-03	8-31
AMBIENT	$\bar{x}$[a]	.047	.026	.028
	s[b]	.015	.004	.016
+2 C	$\bar{x}$	.045	.027	.035
	s	.004	.005	.002
+4 C	$\bar{x}$	.047	.042	.064
	s	.016	.017	.012
+6 C	$\bar{x}$	.040	.033	.061
	s	.016	.002	.021

[a] Treatment mean (n = 9).

[b] Standard deviation (±).

TABLE 46. PERIPHYTON NET OXYGEN PRODUCTION (GM M^{-2} HR^{-1}) - POOL 2.

TEMPERATURE REGIMEN	1977:	4-25	5-12	6-09	7-06	8-03	8-31
AMBIENT	$\bar{x}$[a]	1.06	.05	.66	.20	.13	.12
+2 C	$\bar{x}$	.35	.09	.24	.27	.15	.18
+4 C	$\bar{x}$	.51	.10	.35	.22	.24	.32
+6 C	$\bar{x}$	.67	.12	.62	.26	.35	.20

[a] Treatment mean (n = 3).

TABLE 47. PERIPHYTON ASSIMILATION RATIO (GM O_2 HR^{-1} GM^{-1} CHL A).

TEMPERATURE REGIMEN	1977:	4-25	5-12	6-09	7-06	8-03	8-31
AMBIENT	$\bar{x}$[a]	4.2	0.4	4.1	5.6	2.9	2.4
+2 C	$\bar{x}$	8.0	1.0	6.4	2.9	2.7	2.5
+4 C	$\bar{x}$	7.6	1.8	5.4	2.2	2.3	2.5
+6 C	$\bar{x}$	11.6	2.4	4.2	2.9	3.0	2.6
	ANOVA[b]	ns	ns	ns	$P>.01$	ns	ns

[a] Treatment mean (n = 3).

[b] Analysis of variance of treatment (temperature) effect; ns - not significant ($P>.05$).

TABLE 48. TETRAZOLIUM VIOLET (ETS) ACTIVITY - POOL 2.

TEMPERATURE REGIMEN		ML O_2 M^{-2} HR^{-1}				UL O_2 HR^{-1} MG^{-1} CHL A				UL O_2 HR^{-1} MG^{-1} PROTEIN			
		6-09	7-06	8-03	8-31	6-09	7-06	8-03	8-31	6-09	7-06	8-03	8-31
AMBIENT	$\bar{x}$[a]	-[c]	1.09	1.71	1.28	-	31	45	25	-	3.2	2.7	4.1
	s[b]	-	.69	1.30	.56	-	22	26	6	-	1.3	1.0	.9
+2 C	$\bar{x}$	-	2.61	1.92	1.67	-	30	35	21	-	3.8	3.0	4.0
	s	-	1.52	.31	1.17	-	4	8	5	-	.8	.8	2.1
+4 C	$\bar{x}$	.69	2.98	1.72	1.81	15	28	17	14	1.5	3.3	2.2	4.7
	s	.33	2.79	.30	.35	8	18	7	1	.1	2.2	.2	.4
+6 C	$\bar{x}$	1.48	2.23	3.42	1.11	24	30	29	14	4.0	2.6	3.8	4.4
	s	1.24	1.79	1.23	.50	10	22	4	1	1.0	.4	.9	.4
					ANOVA[d]:		ns	P>.06	P>.01		ns	ns	ns

---

[a] Treatment mean (n = 3).

[b] Standard deviation (±).

[c] Data not available.

[d] Analysis of variance of treatment (temperature effect; ns - not significant (P>.10).

TABLE 49. REGRESSION EQUATIONS FOR THE DEPENDENT VARIABLES NET OXYGEN AND PRODUCTION AND TETRAZOLIUM VIOLET (ETS) ACTIVITY.

DATE	EQUATION	COEFFICIENT OF DETERMINATION (R^2)
7-6-77	$[O_2]$[a] = 0.721 * [carbohydrate] + 2.61	.76
	[TV] + 1.183 * [protein] - 3.023	.78
8-3-77	$[O_2]$ = 0.882 * [chlorophyll a] + 1.246	.93
	[TV] = 0.41 * [chlorophyll a] + 0.797 * [protein] - 0.484 * [carbohydrate] - 2.528	.88
8-31-77	$[O_2]$ = 1.107 * [chlorophyll a] - 0.288 * [protein] + 1.506	.89
	[TV] = 1.055 * [chlorophyll a] - 4.032 * [temperature] + 4.143	.87

---

[a] The brackets around each parameter signifies the $\log_{10}$ concentration.

APPENDICES

TABLE A-1. SAMPLES TAKEN IN BIOTHERMAL CHANNELS.

Date 1977	Type of Sample	Pool or Rock Area
3-2	W*	1, 3
3-24	C*	2
3-30	R	1
4-5	W	1, 3
4-27	R	1
5-2	W	1, 3, 6
5-6	C	2
5-11	R	2
5-27	R	1
6-6	W	1, 3, 6
6-10	C	2
6-28	R	1, 6
7-1	W	1, 3, 6
7-7	C	2, 6
7-28	R	1, 6
8-2	W	1, 3, 6
8-8	C	2, 6
8-31	R	1, 6
9-2	W	1, 3, 6

W - Wall Scraping
C - Core
R - Rock Tray
* - Not Subsampled

TABLE A-2. ANOVA IN PLEXIGLAS SUBSAMPLER.

	N	$\overline{X}$	95% Conf. Int.	S	S^2	C.V.
Wall Scrapings						
Amphipoda	10	3.70	0.79	1.27	1.61	0.34
Chironomidae	10	27.40	2.65	4.27	18.22	0.15
Caenis	10	12.60	1.93	3.11	9.70	0.25
Gastropoda	10	27.40	4.34	7.00	49.04	0.25
Hydroptilidae	10	1.10	0.53	0.87	0.77	0.79
Total Organisms	10	72.10	8.57	13.83	191.29	0.19
Rock Trays						
Amphipoda	8	2.50	0.50	1.41	2.00	0.56
Chironomidae	8	11.75	0.70	1.98	3.93	0.17
Caenis	8	7.88	0.95	2.69	7.26	0.34
Gastropoda	8	3.25	0.48	1.39	1.93	0.42
Erpobdella	8	6.25	0.53	1.49	2.21	0.24
Cores						
Amphipoda	10	7.6	1.74	2.80	7.84	0.36
Chironomidae	10	3.0	0.96	1.55	2.4	0.52
Caenis	10	4.4	1.08	1.74	3.04	0.40
Gastropoda	10	40.9	4.77	7.69	59.09	0.18
Oligochaeta	10	12.2	2.72	4.38	19.16	0.35
Total Organisms	10	71.00	8.78	14.17	200.8	0.19

TABLE A-3. DRY WEIGHTS (MEAN mg m^{-2}) OF DOMINANT TAXA AND TOTAL MACROINVERTEBRATE TAXA EXCLUDING MOLLUSCA IN THREE HABITATS (ROCKS, WALLS, POOLS) AND FOUR TEMPERATURE TREATMENTS.

		Total Macroinvert. excluding Mollusca	Total Gastropoda	*Physa* and/or *Lymnaea*	*Pyrgulopsis*	Amphipoda	*Caenis*	Chironomidae	Hirudinea	*Enallagma*	Libellulidae	Trichoptera
						Rocks						
Mar. 30	A	561	9040	9040		52	278	22	194	15		
	+2 C	601	8055	8055		145	228	37	140	57		
	+4 C	2549	2512	1697	819	761	1045	12	302	124	315	
	+6 C	3916	1906	1906		65	768	9	1996	235	843	
Apr. 27	A	532	1632	1632		175	68	57	233			
	+2 C	1332	2617	2383	234	587	78	249	154		239	
	+4 C	3698	1974	1153	821	743	138	77	707	134	1898	
	+6 C	3958	288	288		96	200	122	75	118	3347	
May 11	A	723	1014	1014		128	53	66	226	8	229	
	+2 C	1858	607	607		390	27	175	182		1084	
	+4 C	9805	593	593		130	299	26	38		9310	
	+6 C	16289	236	236		23	983	314	21	76	14872	
May 31	A	996	58	58		80	46	115	756			
	+2 C	1644	510	510		452	874	209	109			
	+4 C	1748	8658		8658	171	961	420	196			
	+6 C	3146	43	43		47	1968	1072	49			
Jun. 28	A	1603	79	28		243	441	40	657	63		92
	+2 C	1646	85	18		380	342	14	283	144		76
	+4 C	861	982	758		33	462	45	164	2		40
	+6 C	602	5774	5625		1	333	90	68	39		42
Jul. 28	A	893	337	331	6	46	297	96	193		19	111
	+2 C	511	1059	765	294	3	224	45	24		159	22
	+4 C	406	3374	2364	1010		203	41	43		102	11
	+6 C	289	4756	4756			204	31	30		5	20
Aug. 31	A	640	949	535			120	101	11		193	27
	+2 C	279	670	620	50		82	42	86		57	9
	+4 C	139	2997	1222	1775		31	10	46		49	
	+6 C	146	4114	4114			35	54	13		24	3

(continued)

TABLE A-3 (continued).

		Total Macroinverts. excluding Mollusca	Total Gastropoda	*Physa* and/or *Lymnaea*	*Pyrgulopsis*	Amphipoda	*Caenis*	Chironomidae	Hirudinea	*Enallagma*	Libellulidae	Trichoptera
						Walls						
Mar. 2	A	113	3089	3089		24	30	57	1			
	+2 C	129	3670	3670		86	4	22		6		
	+4 C	445	929	876	53	99	30	42	6	38	229	
	+6 C	561	2762	2762		80	42	5		135	242	
Apr. 5	A	35	6319	6319		1	21	13				
	+2 C	10	3585	3486	99	2	1	7				
	+4 C	37	2783	2006	777	23	4	7				
	+6 C	72	2405	2405		13	12				42	
May 2	A	211	3072	3072		54	49	30	7		70	
	+2 C	113	944	906	38	47	8	26			32	
	+4 C	80	1668	1048	620	23	4	7			46	
	+6 C	196	181	179	2	13	44	16	6		117	
Jun. 6	A	156	924	924		72	55	20	2			
	+2 C	279	257	178	79	145	54	53				
	+4 C	163	1665	628	1037	64	61	34	1	2		
	+6 C	119	1318	1248	70	21	61	21		3	13	
Jul. 1	A	394	737	701	40	260	55	2		32	3	27
	+2 C	101	670	160	510	61	18	2		12		8
	+4 C	60	1164	377	790	8	37	1		1		8
	+6 C	47	1747	1609	140	3	11	1		1	26	4
Aug. 2	A	200	1200	1027	173	36	26	36			42	4
	+2 C	142	1047	705	342	4	102	10			16	4
	+4 C	43	4571	1327	3244		13	3			20	3
	+6 C	38	1653	1522	131		18	9			1	3
Sept. 2	A	75	2742	456	2	6	5	11			42	11
	+2 C	54	574	259	315		14	9			28	3
	+4 C	21	809	217	592		3	1			16	1
	+6 C	65	199	188	11		6	4			54	1

(continued)

TABLE A-3 (continued).

		Total Macroinverts. excluding Mollusca	Total Gastropoda	*Physa* and/or *Lymnaea*	*Pyrgulopsis*	Amphipoda	*Caenis*	Chironomidae	Hirudinea	*Enallagma*	Libellulidae	Trichoptera
						Pools						
Mar. 24	A	3066	236	236			17	1021	1742			
	+2 C	533	6944	6944				38	494			
	+4 C	1142	669				117	217	808			
	+6 C	408	481	481			32		375		15041	
May 6	A	3366	608	608				374	2993			
	+2 C	1086						105	947			
	+4 C	8383						888	7494			
	+6 C	4570							4570			
Jun. 10	A	678	6445	6445		193		191	293			
	+2 C	2995	299	299		212	140	1661	983			
	+4 C	1106	9540	7997			255	851				
	+6 C	1539	300	300			239	1246				
Jul. 7	A	2378	3992	3992		457	542	546	208			
	+2 C	2281	418	418		23	160	1313	600			
	+4 C	440	3467	2695	772	2	93	268				
	+6 C	404	4678	4678			30	216	86			
Aug. 8	A	2956	5146	5416			93	1669	187			
	+2 C	777	49		29		33	287				
	+4 C	565	1264	166	1098		14	275				
	+6 C	378	144	144			2	322				

TABLE A-4. DENSITIES (MEAN no m^{-2}) OF MACROINVERTEBRATES IN THREE HABITATS (ROCKS, WALLS, POOLS) AND FOUR TEMPERATURE TREATMENTS.

		Total Macroinverts.	Total Gastropoda	Physa	Lymnaea	Pyrgulopsis	Helisoma	Pleurocera	Corbicula	Total Amphipoda	Hyalella	Crangonyx	Caenis	Hexagenia	Callibaetis	Chironomidae	Total Hirudinea	Erpobdella	Helobdella and/or Placobdella	Oligochaeta	Enallagma	Libellulidae	Trichoptera	Ceratopogonidae	Hydracarina	Hydrophilidae	Dugesia	Corixidae	Nematoda	Collembola	Berosus
ROCKS																															
Mar. 30	A	1165	407	396	10		1			124	77	47	489			117	8	8			1		1	4	13						
	+2 C	4287	3270	3263	1	6	1			502	311	191	375	1		96	12	11	1		6			14	7				1		
	+4 C	6454	2324	2166	5	153				2556	1913	643	1369	1	1	93	17	17			25	6	2	14	43	2	1				
	+6 C	4032	1672	1636	36					358	215	143	1707			82	94	94			24	47		12	36						
Apr. 27	A	5833	3155	3155			24			1052	490	562	108			1159	48	48		60			12	36	155				24		
	+2 C	7638	1113	1047		72				3382	2199	1183	84			1757	932	143	789	275		24			60			12			
	+4 C	8284	1028	849		179	12			4351	2438	1913	215			801	1435	120	1315	179	36	48			131				48		
	+6 C	4519	514	514						1565	1063	502	813			1064	179	143	36	72	12	179	24						96	1	
May 11	A	3061	1303	1279	24		48			801	215	586	84			263	359	359		131	12	12		48							
	+2 C	3733	383	383						1842	1447	395	347			598	299	299		108		12	12	84	24				24		
	+4 C	3720	395	383				12		920	693	227	1207			299	598	562	36	72		108	48	12	37				12		
	+6 C	5146	203	203						120	96	24	2116			1877	36	36		323	4	359			60				48		
May 31	A	1267	48	36	12					323	48	275	156			514	215	215							12						
	+2 C	7880	120	120						2702	2224	478	2367			2247	156	156		108			119		36				24		
	+4 C	9008	538	48		490			12	1280	789	491	2713			3813	263	132	131	108	18		203	12	48				24		
	+6 C	12542	36	24	12					478	442	36	5821		36	5655	120	60	60				287	12	72						
Jun. 28	A	6353	12	6	6					1572	1327	245	2438			269	627	137	490	735	42	6	550	12	66						24
	+2 C	7443	54	36		18				2522	2486	36	1830			126	239	54	185	1363	48		442	36	84		699				
	+4 C	5559	628	502		126			6	275	275		2235		6	532	257	36	221	687	6	6	251	18	173		150		18		
	+6 C	4733	1297	1208		89				30	30		2235			532	126	18	108	155	12		233	12	60		30		12		
Jul. 28	A	5411	193	186		6	6			543	394	149	2361			801	257	72	185	60		30	873	30	197		36	6	18		
	+2 C	5556	359	233		126				18	18		3395	2		424	54	6	48	640	6	42	203		329		84				
	+4 C	3250	1010	502		508			6				1387			359	54	18	36	149		15	78	6	120		6		60		
	+6 C	3617	1040	1040									1859			335	18	6	12	96		6	132	6	72		12		42		
Aug. 31	A	3850	199	197				2	12	36		36	1034			933	18	12	6	1160		6	79		293		42				
	+2 C	1010	138	120		18							425			293	12	12		18		4	48		60				12		
	+4 C	1428	1165	179		957		29					144			42	30	24	6	18		10							12		
	+6 C	1193	592	592									180			281	12	6	6	30	6	8	6		18				60		

(continued)

TABLE A-4 (continued).

POOLS		Total Macroinverts.	Total Gastropoda	Physa	Lymnaea	Pyrgolopsis	Corbicula	Pleurocera	Total Amphipoda	Hyalella	Crangonyx	Caenis	Chironomidae	Total Hirudinea	Erpobdella	Helobdella and/or Placobdella	Oligochaeta	Ena'lagma	Libellulidae	Trichoptera	Ceratopogonidae	Nematoda	Hydracarina	Polychaeta	Corixidae	Berosus
Mar. 24	A	2876	53	35	18		53	18				88	2139	158	158		333				35					
	+2 C	1823	298	298			193					18	210	70	70		999				35					
	+4 C	1455	18				158		53	53		245	544	88	88		350									
	+6 C	667	35	35								105		35	35		368		123							
May 6	A	7833	2104	2104			701		234	234			2455	701	701		1403				233					
	+2 C	5378					1286		234	234		116	1052	451	117	234	1987					351				
	+4 C	7599	585	585			116					585	3156	468	468		2338					351				
	+6 C	3344											1052	234	234		1871		70			117				
Jun. 10	A	9587	3156	3156					1754	1754		234	1754	117	117		2572									
	+2 C	14964	4326	4326					1169	1169		935	5845	117	117		1520			234		818				
	+4 C	17302	3976	3391		585			234	234		1169	9353	117		117	1520	117		701					117	
	+6 C	8885	468	468								1052	6079				1169				117					
Jul. 7	A	19640	4092	4092			58	58	3507	3507		2397	3975	526	58	468	2923			935	935		175			
	+2 C	13917	1228	1228			64		234	234		1520	8826	175	175		994			234	468		175			58
	+4 C	7189	2163	1871		292			117	117		1111	2689				701			58			351			
	+6 C	4386	1286	1286								176	2048	58	58		643			59	58	58				
Aug. 8	A	25779	2163	2163					58		58	877	17186	58	58		3566			818	643	175	234			
	+2 C	6021	59			59	175					117	1988				2981			59	58	292	292			
	+4 C	5613	1112	234		878						117	1520				1929			117	58	468	234	58		
	+6 C	2981	117			117						59	1754				409			58		292	292			

TABLE A-4 (continued).

		Total Macroinverts.	Total Gastropoda	Physa	Lymnaea	Pyrgolopsis	Helisoma	Pleurocera	Corbicula	Total Amphipoda	Hyalella	Crangonyx	Caenis	Callibaetis	Chironomidae	Total Hirudinea	Erpobdella	Helobdella and/or Placobdella	Oligochaeta	Enallagma	Libellulidae	Trichoptera	Corixidae	Tipulidae	Ceratopogonidae	Nematoda	Haliplidae	Berosus	Collembola	Hyrdacarina	Dugesia
WALLS																															
Mar. 2	A	618	227	213	13		1			47	31	16	190		131																
	+2 C	636	240	236	4					302	284	18	16		76					1											
	+4 C	1073	97	86	11					510	495	15	232		136					3	2										
	+6 C	1041	466	391	75					205	191	14	314		47					5	3										
Apr. 5	A	3123	2897	2873	7		17			12	6	6	70		117															27	
	+2 C	2540	2307	2277		30			10	127	127		17		60							7								13	
	+4 C	1891	1622	1466		157			3	203	200	3	33		17															13	
	+6 C	1391	1077	1060	17					127	127		120			7	7				23									37	
May 2	A	3709	2940	2916	11		13			224	195	29	142		318						1	2								53	
	+2 C	2650	1511	1504		7			7	380	369	11	264		427	4	4		13		1	9	2							33	
	+4 C	1909	1437	1293	30	114				133	131	2	162		118						4	4			2	2				47	
	+6 C	1382	269	238	13	18				129	120	9	700		169						2	13								29	
Jun. 6	A	2077	948	942	7					529	511	18	269	7	233				27			40				2		2		20	
	+2 C	2326	171	142		29			2	1066	1062	4	324	7	536				140	4		42	2		4					27	
	+4 C	2387	831	524	7	300	2			477	473	4	407	2	389	2	2		127	20		44				11				24	51
	+6 C	2430	997	940	4	53				153	153		660	7	418				67	13	6	60			4	7				36	2
Jul. 1	A	3888	1119	1097	11		9	2		1956	1956		382	2	20	20		20	127	22	7	158		2	4			2		56	
	+2 C	1587	508	228		280				647	647		178		84	2		2	60	4		56			2	24			2	20	
	+4 C	1298	920	313	40	567				98	98		149		36				11	2		27	4		9	18				24	
	+6 C	1131	608	531	4	73				20	20		307		122				11	2	4	33				4				20	
Aug. 2	A	1736	391	371	9			11		391	391		540		318	2		2	13		14	18			16		2			29	2
	+2 C	1468	783	356		427				44	44		360		184				4	2	1	33			4				11	42	
	+4 C	2110	1807	413		1387	7						164		47						1	18			4	51				18	
	+6 C	962	411	338		71	2						236	7	178					7	1	24			2	60				36	
Sept. 2	A	513	82	64		2	2	14		91	91		44		202	1	1					38			2					53	
	+2 C	726	318	102		216							136		180						3	13				29				47	
	+4 C	1418	1235	182		1053							44		31						1	16				69				22	
	+6 C	458	111	100		11							136		136				2		1	16				36				20	

(continued)

TABLE A-5. ANOVA OF TREATMENT EFFECTS ON *P. LETSONI* DENSITY (no m^{-2}) AND DRY WEIGHT (mg m^{-2}) IN THREE HABITATS.

Date	Sample Loc.†	P	Parameter	N	Treatment Effects
3-2	W	N.S.	no	44	
		0.05	mg	44	+4 > A = +2 = +6
3-24	P	N.S.	no	8	
		N.S.	mg	8	
3-30	R	N.S.	no	36	
		0.01	mg	33	+4 > A = +2 = +6
4-5	W	N.S.	no	24	
		0.05	mg	24	+4 > A = +6
4-27	R	N.S.	no	12	
		N.S.	mg	12	
5-1	W	N.S.	no	36	
		0.01	mg	36	+4 > A = +2 = +6
		N..S	mg	12	
5-11	R	N.S.	no	12	
		N.S.	mg	12	
5-31	R	0.01	no	12	+4 > A = +2 = +6
		N.S.	mg	12	
6-6	W	N.S.	no	36	
		0.01	mg	36	+4 > A = +2 = +6
6-10	P	N.S.	no	12	
		N.S.	mg	12	
6-28	R		no		
			mg		
7-1	W	0.05	no	36	+4 > A = +2 = +6
		N.S.	mg	36	
7-7	P	N.S.	no	24	
		N.S.	mg	24	
7-28	R	0.05	no	24	+4 > A = +2 = +6
		0.01	mg	24	+4 > A = +2 = +6
8-2	W	0.05	no	36	+4 > +2 > A = +6
		0.05	mg	36	+4 > A = +2 = +6
8-8	P	0.01	no	24	+4 > A = +2 = +6
		0.01	mg	24	+4 > A = +2 = +6
8-31	R	0.01	no	24	+4 > A = +2 = +6
		0.01	mg	24	+4 > +2 > A = +6
9-2	W	0.05	no	36	+4 > +2 = A = +6 +2 > A
		0.05	mg	36	+4 > +2 = A = +6 +2 > A

† W - Walls
P - Pool Sediments
R - Rock Areas

TABLE A-6. ANOVA OF TREATMENT EFFECTS ON GASTROPODA* DENSITY (no m^{-2}) AND DRY WEIGHT (mg m^{-2}) IN THREE HABITATS.

Date	Sample Loc.†	P	Parameter	N	Treatment Effects
3-2	W	N.S.	no	44	
		N.S.	mg	44	
3-24	P	N.S.	no	8	
		N.S.	mg	8	
3-30	R	N.S.	no	36	
		N.S.	mg	33	
4-5	W	N.S.	no	24	
		N.S.	mg	24	
4-27	R	N.S.	no	12	
		N.S.	mg	12	
5-1	W	0.01	no	36	A = +2 = +4 > +6
		N.S.	mg	36	
5-6	P	N.S.	no	12	
		N.S.	mg	12	
5-11	R	N.S.	no	12	
		N.S.	mg	12	
5-31	R	N.S.	no	12	
		N.S.	mg	12	
6-6	W	0.05	no	36	A = +4 = +6 > +2
		0.05	mg	36	A = +4 = +6 > +2
6-10	P	N.S.	no	12	
		N.S.	mg	12	
6-28	R	0.01	no	24	+4 = +6 > A = +2
		0.01	mg	24	+4 > A = +2 = +6
7-1	W	N.S.	no	36	
		N.S.	mg	36	
7-7	P	N.S.	no	24	
		N.S.	mg	24	
7-28	R	0.05	no	24	+4 = +6 > A = +2
		0.05	mg	24	+4 = +6 > A = +2
8-2	W	N.S.	no	36	
		N.S.	mg	36	
8-8	P	0.05	no	24	A = +4 > +2 = +6
		N.S.	mg	24	
8-31	R	N.S.	no	24	
		0.05	mg	24	+4 = +6 > A = +2
9-2	W	0.05	no	36	+2 = +4 = +6 > A
		N.S.	mg	36	

* no - *P. heterostropha*
mg - *P. heterostropha* and *Lymnaea* sp.

† W - Walls
P - Pool Sediments
R - Rock Areas

TABLE A-7. ANOVA OF TREATMENT EFFECTS ON TOTAL GASTROPODA DENSITY (no m^{-2}) IN THREE HABITATS.

Date	Sample Loc.†	P	N	Treatment Effects
3-2	W	N.S.		
3-24	P	N.S.	8	
3-30	R	N.S.	36	
4-5	W	0.05	24	A = +2 > +6
4-27	R	N.S.	12	
5-1	W	0.01	36	A > +2 = +4 > +6
5-6	P	N.S.	12	
5-11	R	N.S.	12	
5-31	R	N.S.	12	
6-6	W	0.05	36	A = +4 = +6 > +2
6-10	P	N.S.	12	
6-28	R	0.05	24	+4 = +6 > +2 > A
7-1	W	N.S.	36	
7-7	P	N.S.	24	
7-28	R	0.05	24	+4 = +6 > A = +2
8-2	W	N.S.	36	
8-8	P	0.05	24	A = +4 > +2 = +6
8-31	R	0.01	24	+4 = +6 > A = +2
9-2	W	0.01	36	+4 > A = +2 = +6

† W - Walls
P - Pool Sediments
R - Rocks

TABLE A-8. PERCENT ABUNDANCE OF MACROINVERTEBRATE TAXA IN THREE HABITATS (ROCKS, WALLS, POOLS) AND FOUR TEMPERATURE TREATMENTS.

		Physa	*Lymnaea*	*Pyrgulopsis*	*Caenis*	Chironomidae	*Hyalella*	*Crangonyx*	Total Amphipoda	Libellulidae	Trichoptera	*Erpobdella*	*Helobdella* and/or *Placobdella*	Oligochaeta	Hydracarina	Others
								Rocks								
Mar. 30	A	33	0	0	41	10	6	4	10	0	0	0	0	0	1	5
	+2 C	76	0	0	8	2	7	4	11	0	0	0	0	0	0	3
	+4 C	33	0	2	21	1	29	9	38	0	0	0	0	0	0	5
	+6 C	40	0	0	42	2	5	3	8	1	0	2	0	0	0	5
Apr. 27	A	54	0	0	1	19	8	9	17	0	0	0	0	1	2	6
	+2 C	13	0	0	1	23	28	15	43	0	0	1	10	3	0	6
	+4 C	10	0	2	2	9	29	23	52	0	0	1	15	2	1	6
	+6 C	11	0	0	17	23	23	11	44	3	0	3	0	1	0	8
May 11	A	41	0	0	2	8	7	19	26	0	0	11	0	4	0	8
	+2 C	10	0	0	9	16	38	10	48	0	0	8	0	2	0	7
	+4 C	10	0	0	32	8	18	6	24	2	1	15	0	1	0	7
	+6 C	3	0	0	41	36	1	0	1	6	0	0	0	6	1	6
May 31	A	2	0	0	12	40	3	21	24	0	0	16	0	0	0	6
	+2 C	1	0	0	30	28	28	6	34	0	1	1	0	1	0	4
	+4 C	0	0	5	30	42	8	5	13	0	2	1	1	1	0	5
	+6 C	0	0	0	46	45	3	0	3	0	2	0	0	0	0	4
Jun. 28	A	0	0	0	38	4	20	3	23	0	8	2	7	11	1	6
	+2 C	0	0	0	24	1	33	0	33	0	5	0	2	18	1	7
	+4 C	9	0	2	40	9	4	0	4	0	4	0	3	12	3	12
	+6 C	25	0	1	47	11	0	0	0	0	4	0	2	3	1	6
Jul. 28	A	3	0	0	43	14	7	2	9	0	16	1	3	1	3	7
	+2 C	4	0	2	61	7	0	0	0	0	3	0	0	11	5	6
	+4 C	15	0	15	42	11	0	0	0	0	2	0	1	4	3	7
	+6 C	28	0	0	51	9	0	0	0	0	3	0	0	2	1	6
Aug. 31	A	5	0	0	27	24	0	0	0	0	2	0	0	30	0	11
	+2 C	11	0	0	1	42	29	0	0	0	4	1	0	1	0	6
	+4 C	12	0	67	10	2	0	0	0	0	0	1	0	1	0	7
	+6 C	49	0	0	15	23	0	0	0	0	0	0	0	2	1	10

(Continued)

TABLE A-8 (continued).

		Physa	*Lymnaea*	*Pyrgulopsis*	*Caenis*	Chironomidae	*Hyalella*	*Crangonyx*	Total Amphipoda	Trichoptera	Oligochaeta	Hydracarina	Nematoda	Others
							Walls							
Mar. 2	A	34	2	0	30	21	5	2	7	0	0	0	0	6
	+2 C	37	0	0	2	11	44	2	46	0	0	0	0	4
	+4 C	8	1	0	21	12	46	1	47	0	0	0	0	11
	+6 C	37	7	0	30	4	18	1	19	0	0	0	0	3
Apr. 5	A	91	0	0	2	3	0	0	0	0	0	0	0	4
	+2 C	89	0	1	0	2	5	0	5	0	0	0	0	3
	+4 C	77	0	8	1	0	10	0	10	0	0	0	0	4
	+6 C	76	1	0	8	0	9	0	9	0	0	0	0	4
May 2	A	79	0	0	3	8	5	0	5	0	0	1	0	4
	+2 C	56	0	0	9	16	13	0	13	0	0	1	0	5
	+4 C	67	1	5	8	6	6	0	6	0	0	2	0	5
	+6 C	17	0	1	50	12	8	0	8	0	0	2	0	10
Jun. 6	A	45	0	0	12	11	24	0	24	1	1	0	0	6
	+2 C	6	0	1	13	22	45	0	45	1	6	0	0	6
	+4 C	21	0	12	17	16	19	0	19	1	5	1	0	8
	+6 C	38	0	2	27	15	7	0	7	1	2	1	0	7
Jul. 1	A	28	0	0	9	0	50	0	50	4	3	1	0	5
	+2 C	14	0	17	11	5	40	0	40	3	3	1	1	5
	+4 C	24	3	43	11	2	7	0	7	2	0	1	1	6
	+6 C	46	0	6	23	10	1	0	1	2	0	1	0	11
Aug. 2	A	22	0	0	31	18	22	0	22	0	0	1	0	6
	+2 C	24	0	28	24	12	2	0	2	2	0	2	0	6
	+4 C	19	0	65	7	2	0	0	0	0	0	0	0	7
	+6 C	35	0	7	25	18	0	0	0	2	0	3	0	10
Sept. 2	A	12	0	0	8	39	17	0	17	7	0	10	0	7
	+2 C	14	0	29	18	24	0	0	0	1	0	6	3	5
	+4 C	12	0	74	3	2	0	0	0	1	0	1	4	3
	+6 C	22	0	2	30	30	0	0	0	3	0	4	7	2

(continued)

TABLE A-8 (continued).

		Physa	*Pyrgulopsis*	*Caenis*	Chironomidae	*Hyalella*	Libellulidae	Trichoptera	*Erpobdella*	Oligochaeta	*Corbicula*	Ceratopogonidae	Nematoda	Hydracarina	Others
							Pools								
Mar. 24	A	1	0	3	74	0	0	0	5	11	1	1	0	0	4
	+2 C	16	0	0	11	0	0	0	3	54	10	1	0	0	5
	+4 C	1	0	16	37	3	0	0	6	24	10	0	0	0	3
	+6 C	5	0	15	0	0	18	0	5	55	0	0	0	0	2
May 6	A	26	0	0	31	2	0	0	8	17	8	2	0	0	6
	+2 C	0	0	2	19	4	0	0	2	36	23	0	6	0	8
	+4 C	7	0	7	41	0	0	0	6	30	1	0	4	0	4
	+6 C	0	0	0	31	0	2	0	6	55	0	0	3	0	3
Jun. 10	A	32	0	2	18	18	0	0	1	26	0	0	0	0	3
	+2 C	28	0	6	39	7	0	1	0	10	0	0	5	0	4
	+4 C	19	3	6	54	1	0	4	0	8	0	0	0	0	5
	+6 C	5	0	11	68	0	0	0	0	13	0	0	0	0	3
Jul. 7	A	20	0	12	20	17	0	4	0	14	0	4	0	0	8
	+2 C	8	0	10	63	1	0	1	1	7	0	3	0	1	5
	+4 C	26	4	15	37	1	0	0	0	9	0	0	0	4	4
	+6 C	29	0	4	46	0	0	1	1	14	0	1	1	0	3
Aug. 8	A	8	0	3	66	0	0	3	0	13	0	2	0	0	5
	+2 C	0	0	1	33	0	0	0	0	49	2	0	4	4	7
	+4 C	4	15	2	27	0	0	2	0	34	0	1	8	4	3
	+6 C	0	3	1	58	0	0	1	0	13	0	0	9	9	6

TABLE A-9. PERCENT DRY WEIGHT OF DOMINANT MACROINVERTEBRATE TAXA EXCLUDING MOLLUSCA IN THREE HABITATS (ROCKS, WALLS, POOLS) AND FOUR TEMPERATURE TREATMENTS.

		Caenis	Chironomidae	Amphipoda	Hirudinea	*Enallagma*	Libellulidae	Trichoptera	Oligochaeta	Others
	Rocks									
Mar.30	A	49	3	9	34	2				3
	+2 C	37	6	24	23	9				1
	+4 C	40		29	11	4	12			4
	+6 C	19		1	50	6	21			3
Apr. 27	A	12	10	32	43					3
	+2 C	5	18	44	11		17			5
	+4 C	3	2	20	19	3	51			2
	+6 C	5	3	2	1	2	84			3
May 11	A	7	9	17	31	1	31			4
	+2 C	1	9	20	9		58			3
	+4 C	3		1			94			1
	+6 C	6	1				91			3
May 31	A	4	11	8	75					2
	+2 C	53	12	27	6					2
	+4 C	54	24	9	11					2
	+6 C	62	34	1	1					2
Jun. 28	A	27	2	15	40	3		5		8
	+2 C	20		23	17	8		4		
	+4 C	53	5	3	19			4		
	+6 C	55	14		11	6		6		
Jul. 28	A	33	10	5	21		2	12		17
	+2 C	43	8		4		31	4		10
	+4 C	50	10		10		25	2		3
	+6 C	71	10		10		1	6		2
Aug. 31	A	18	15		1		30	4	24	8
	+2 C	29	15		30		20	3	1	2
	+4 C	22	7		33		35		2	1
	+6 C	23	36		8		16	2	1	12

(continued)

TABLE A-9 (continued).

		Caenis	Chironomidae	Amphipoda	*Enallagma*	Libellulidae	Trichoptera	Others
	Walls							
Mar. 2	A	26	50	21				3
	+2 C	3	17	66	4			10
	+4 C	6	9	22	8	51		4
	+6 C	7		14	24	43		12
Apr. 5	A	60	37	2				1
	+2 C	10	70	20				
	+4 C	10	18	62				10
	+6 C	16		17		57		10
May 2	A	23	14	25		33		5
	+2 C	7	23	41		28		1
	+4 C	5	8	28		57		2
	+6 C	22	8	6		59		5
Jun. 6	A	35	12	46				7
	+2 C	19	18	51				2
	+4 C	37	20	39	1			3
	+6 C	51	17	17	2	10		3
Jul. 1	A	13		65	8		6	8
	+2 C	17	1	60	11		7	4
	+4 C	61	1	13	1		13	11
	+6 C	23	2	6	2	55	8	4
Aug. 2	A	13	18	18		21	2	28
	+2 C	71	7	2		11	2	7
	+4 C	30	6			46	6	12
	+6 C	47	23			2	7	21
Sept. 2	A	6	14	8		55	14	3
	+2 C	25	16			51	5	3
	+4 C	14	4			76	4	2
	+6 C	9	6			83	1	1

(continued)

TABLE A-9 (continued).

		Caenis	Chironomidae	Amphipoda	Trichoptera	Hirudinea	Oligochaeta	Libellulidae	Others
	Pools								
Mar. 24	A		33			56			11
	+2 C		7			92			1
	+4 C	10	19			70			1
	+6 C					2		97	1
May 6	A		11			88			1
	+2 C		9			87			4
	+4 C		10			89			1
	+6 C					100			
Jun. 10	A		28	28		43			1
	+2 C	4	55	7		32			2
	+4 C	23	76						1
	+6 C	15	80						5
Jul. 7	A	19	20	16	4	7	25		9
	+2 C	6	55		1	25	8		5
	+4 C	18	52		1		27		2
	+6 C	6	46		1	18	27		2
Aug. 8	A	3	56		2	6	19		14
	+2 C	4	36				57		3
	+4 C	2	48		1		47		2
	+6 C		85		2		12		1